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ASSESSING NITROGEN REQUIREMENTS OF SOME ALBERTA SOILS

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Krishan N. Synghal

DEPARTMENT OF SOIL SCIENCE

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THE UNIVERSITY OF ALBERTA

ASSESSING NITROGEN REQUIREMENTS OF SOME ALBERTA SOILS

A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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by

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ABSTRACT

In an attempt to develop a practical method of assessing the nitrogen requirements of some Alberta soils, a preliminary study was conducted using a nitrate-nitrogen accumulation test. Promising results were obtained by this study and hence some other tests intended to determine the availability of soil nitrogen were compared with the nitrate-nitrogen accumulation test. Fifty Alberta soils were used and the tests compared were: available nitrogen by the Wisconsin method, 'N' values, total nitrogen in the soil, nitrogen content of the unfertilized plant material, nitrate-nitrogen initially present, and per cent of soil nitrogen mineralized to nitrate. The fifty soils were collected from the six soil zones of Alberta and the study included field data, greenhouse experiments, and laboratory incubations and analyses.

Based on these studies, the various tests may be evaluated as follows:

1. Of the methods tested, the nitrate-nitrogen accumulation test is the one most likely to be useful. The method has the advantages of being quite simple and not very lengthy. It consists of incubating for two weeks at 28°C. soils mixed with vermiculite, followed by determination of the accumulated nitrate-nitrogen.
2. The determination of available nitrogen by the 'N' value procedure is highly correlated with the yield increases obtained from fertilization in the greenhouse. However, this procedure is quite lengthy, laborious, and requires greenhouse facilities. It is not likely to prove practical.
3. The determination of available nitrogen by the Wisconsin method was also found to be correlated with greenhouse crop yields. However, in general the nitrate-nitrogen accumulation test gave a closer correlation.

The Wisconsin method has the advantage of being very simple and rapid.

4. Total soil nitrogen and nitrogen in the unfertilized plant material from the greenhouse experiment did not correlate with yields. Nitrate-nitrogen initially present in the soil and the per cent of total nitrogen mineralized to nitrate were also found to be comparatively poor tests.
5. None of the tests gave a significant correlation with the yield data obtained in the field during 1955 and 1956. A number of reasons have been discussed for the lack of correlation between nitrate-nitrogen accumulation and yields in the field experiments. However, nitrate-nitrogen accumulation in soils was significantly correlated with some of the yield data from field trials conducted in 1957. These results show some possibility of practical applications of this test.

The studies also indicated that:

1. Soils which accumulate less than 80 p.p.m. of nitrate-nitrogen when incubated for two weeks at 28°C. generally respond to nitrogen application in the greenhouse.
2. A considerable proportion of fertilizer nitrogen was taken up by the plants. Under greenhouse conditions 35 to 60 per cent of the applied fertilizer was recovered in crops. The recovery was slightly higher at lower levels of nitrogen application and was also higher when physical conditions were favourable. The unrecovered nitrogen seems to have been lost either through denitrification or by immobilization in the soil.
3. In the greenhouse a single crop did not use all fertilizer nitrogen supplied by the higher rates of application. There was some residual effect on the crop which followed.
4. The amount of available nitrogen coming from the soil decreased with continuous cropping in the greenhouse.

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INTRODUCTION

The need of fertilizer material containing nitrogen for cultivated land was recognized in early agriculture. Some Greek and Roman authors stated that the use of farmyard manure and the growing of legumes were accepted practices for maintaining the fertility of land. Glauber in 1656 reported a great increase in crop yield by the use of saltpeter. Later the need for supplying nitrogen to the soil was stressed by Tull, Liebig, Lawes, and others. It is now generally recognized that an adequate amount of available nitrogen in the soil is one of the prerequisites for good plant growth.

The nitrogen status of soil usually undergoes a gradual deterioration when land is used for agriculture. Cultivation of land upsets the nitrogen equilibrium in the soil. The nitrogen content of the soil usually decreases when land is broken and in later years it may stabilize at a lower level. Modern agricultural developments such as growing of row crops instead of grasses and legumes, introduction of high-yielding varieties, and intensive cultivation practices have also contributed to the lowering of nitrogen supplies in soils.

Problems of maintaining nitrogen supplies for crops may be tackled in a number of ways. Nitrogen may be maintained in the soil by including legumes and grasses in rotations, by the addition of crop residues, by use of farm manure, and by applying commercial fertilizers. In some cases, on better managed lands, nitrogen and organic matter contents may be maintained. However, many investigators have reported the fact that most arable land undergoes a decline in its nitrogen content under cultivation. Soil aeration is increased and this results in a greater rate of mineralization of organic nitrogen which is subsequently lost. The addition of plant remains containing some organic nitrogen is at times lower when land is cultivated than under natural conditions.

In recent years there has been a growing interest in the use of commercial fertilizers to supply the nitrogen needs of crops. The world-wide use of nitrogen fertilizers has shown a manifold increase. The prospects for further use of the nitrogen fertilizer are extensive. For example in parts of Alberta where the nitrogen content of the soil was previously considered adequate, it has been found by field trials that about fifty per cent of the fields do respond to the application of nitrogen in the form of commercial fertilizers.

In order to get higher yields per acre and to have the optimum use of nitrogenous fertilizers, it is important to devise ways of ascertaining what soils and fields are likely to respond to the addition of nitrogen. For this reason a method is desired for soil testing which will determine whether use of fertilizer nitrogen is likely to be profitable. This report deals primarily with investigations carried out in the hope of developing such a test for Alberta soils.

In most of the areas in India there is an increasing awareness of the desirability of adding nitrogen to growing crops. The need for nitrogen there becomes more imperative because of the tropical climate. The temperature throughout the year and especially during the summer is so high that organic matter added to the soil is almost completely decomposed in a very short period. The decomposition of organic matter results in the release of nitrogen from the organic into soluble inorganic forms. The nitrogen thus made available is taken up partly by the growing crops. The remainder is lost either in the runoff resulting from heavy downpours in the rainy season or is leached down to subsoil depth from which very little may be available to the growing crops. For these reasons many Indian soils are lacking in adequate nitrogen supplies. The government of India has decided to manufacture more nitrogenous fertilizers to meet this need. In order to have the best use of

the costly nitrogenous fertilizer, it would be in the national interest if it could be applied on land likely to give the maximum response and thus yield highest profits with minimum outlay.

In undertaking this study it was thought that the results obtained would not only be useful in Alberta but in addition the writer would gain knowledge and experience which he could apply to problems in his own country.

REVIEW OF LITERATURE

A. Essentiality of Nitrogen for Plants

The beneficial effect of nitrogen compounds on plant growth was recognized long ago. The use of saltpeter as a fertilizer was mentioned both by Theophrastus (372-287 B.C.) and Pliny (62-113 A.D.) (quoted by Tisdale and Nelson (160)). In 1656 Glauber (quoted by Russell and Russell (135)) suggested that saltpeter was the 'principle' of vegetation and not water. Glauber argued that saltpeter present in cattle-shed earth must have come from the droppings and urine of animals. Since the animals excreted nitrogen compounds, it must have been present in their food, that is in the plants they ate. He therefore concluded that nitrogen is an essential constituent of plants. He also found that the addition of saltpeter to the soil increased the crop yield tremendously. Glauber's views about the need for nitrogen by the plants were supported by Mayow (quoted by Russell and Russell) who estimated the quantities of nitrates in the soil at various times during the year. Mayow found nitrates present in largest amounts in the spring and in smallest amounts during the summer. He concluded that saltpeter was 'sucked out by plants' during their period of rapid growth. In 1727 Hume (quoted by Russell and Russell) conducted pot culture experiments to study the effects of saltpeter on plant growth. He found the addition of saltpeter led to increased plant growth.

In 1804 Theodore de Saussere (quoted by Russell and Russell) concluded that soil furnished nitrogen, along with the other constituents present in the plant ash, to the plant. He showed that nitrogen was not assimilated directly from the air but was derived from the soil. In 1840 Liebig (quoted by Russell and Russell) stated that plants take up nitrogen in the ammonia form which may come from the soil, from added manure, or from the air. However, in later years he thought that plants could derive their ammonia from the atmosphere as they do carbonic acid. Liebig felt that there was no need to supply ammonia either from the soil or from manure. In 1855 Lawes and Gilbert (quoted by Russell and Russell) concluded that non-leguminous crops require a supply of some nitrogenous compounds and that they must obtain it from the soil. They suggested that the amount of ammonia obtainable from the atmosphere was insufficient for the needs of crops. They also proposed that the beneficial effect of fallowing on the succeeding crop was due to the increase in available nitrogen compounds in the soil. In 1860 Sachs and Knop (quoted by Bonner and Galston (19)) showed quite conclusively that nitrogen is one of the essential elements for plant growth.

B. Sources of Soil Nitrogen

Unlike phosphorus, calcium, magnesium, potassium, etc., nitrogen is not a constituent of the original soil minerals but instead it is part of the atmosphere. The free nitrogen of the atmosphere may be converted to compounds of nitrogen by natural or artificial processes. In nature the free nitrogen enters into combination with other elements through the activities of certain bacteria and other microorganisms present in the soil. Lighting discharges also unite atmospheric nitrogen and oxygen to form oxides of nitrogen. Artificial fixation of atmospheric nitrogen with other elements is brought about through chemical reactions utilizing energy.

Nitrogen may be added to the soil in a number of ways. It may be added through the fixation of atmospheric nitrogen, by legume bacteria, and by non-symbiotic nitrogen-fixing organisms. It may be added by rainwater or snow. It can also be supplied in the form of artificial fertilizers, farm manure, crop residue, compost, etc.

Nitrogen fixation by biological agencies has been and will continue to be one of the most important means of building up the nitrogen content of soil. Walker (177) has stated that in New Zealand the legumes, principally white clover, fix atmospheric nitrogen to meet the need of pasture lands. Lipman and Conybeare (94) estimated that in the year 1930, out of a total of about 16.2 million tons of nitrogen added to the agricultural lands of the United States, 9.8 million tons of nitrogen came from nitrogen fixation through biological agencies. Symbiotic nitrogen fixation as reported by various authors is given in Table I. The figures reported by these authors differ, in certain cases quite appreciably. However, differences in soil and climatic conditions may partly account for such variations. Moreover, certain legumes fix more nitrogen than others. Gustafson (op. cit.) suggested that 80 pounds of nitrogen per acre may be fixed annually by legumes. Lipman and Conybeare had also based their figure of 88 pounds of nitrogen fixation on the reports collected from wide areas. It seems, therefore, that about 80 to 90 pounds of nitrogen may be the average amount fixed annually per acre by common legume crops. If the conditions of aeration, moisture, nutrient supply, calcium availability, etc., are all favourable, it is expected that the amount of nitrogen fixed might be appreciably more than this.

However, it has been pointed out by Newton (112) that it is difficult to determine how much nitrogen is obtained from the air by an inoculated legume crop because part of the nitrogen is obtained from the soil and this proportion varies with the available nitrogen content of the soil.

TABLE I. Estimates of Symbiotic Nitrogen Fixation

Author(s)	Ref. No.	Location	Crop	Nitrogen fixed, Lb./ac./yr.
Bracken and Larson	23	North Utah	Alfalfa	246
Chapman et al.	36	California	Sweet clover and purple vetch	150
Collison et al.	39	Geneva,N.Y.	Alfalfa	260
			Clover	38
Fred et al. (quoted by Gustafson)	68	Wide area including U.S.A. and Canada	Alfalfa	101
			Sweet clover	117
			Red clover	91
			Annual legumes	89
Hall	69	Rothamsted	Mixed herbage having chiefly meadow vetchling as legume	92
Hopkins	82		Legumes grown and harvested	Nil
Lipman and Conybeare	Op.cit.	U.S.A.	Legumes	88
Lyon and Bizzell	96	Ithaca,N.Y.	Alfalfa, continuous	268
			Red clover*	146
			Alsike clover*	136
			Sweet clover*	163
			Alfalfa*	241
			Vetch and wheat*	65
			Red clover and alsike*	163
			Sweet clover and vetch*	156
			Soybeans*	102
			Peas and oats*	46
			Field beans*	57
Renner et al.	128	Alberta	Legume mixture	150
Schreiner and Brown	140	U.S.A.	Legumes	80
Smith	143	Arizona	Alfalfa	100
Swanson and Latshaw	158	Kansas	Alfalfa	125

* Alternating with barley or rye.

Nitrogen is also fixed by certain other bacteria besides the ones present in the nodules of legumes. The most important of these free-living nitrogen-fixing bacteria are Azotobacter and Clostridium. The quantities of nitrogen fixed by non-symbiotic organisms reported by several investigators are given in Table II. Unlike those for symbiotic nitrogen fixation, these results are highly variable. It is thus difficult to state the average amount of nitrogen fixed non-symbiotically. However, Lyon et al. (98) have suggested that 25 pounds of nitrogen fixation annually per acre would be a conservative estimate. In recent years the effect of Azotobacter inoculation of the soil has been studied by some investigators. Allison (4) in his review has concluded that Azotobacter inoculation did not give positive results. Gainey (61) also reported that Azotobacter introduced into the soil did not have any influence upon the nitrogen balance of soil. However, Allison states that large increases in yield have been reported from the U.S.S.R. and millions of acres of land under non-legumes are being inoculated annually there. Allison (3) questions the very validity of the claims made with regard to the non-symbiotically fixed nitrogen. He suggests the nitrogen gains in grass sods that may seem to be real are likely to be only apparent for a variety of reasons. These include sampling error, failure to keep the grass free from legumes, inadequate allowance for addition of nitrogen in the rainfall, inadequate replications, etc. Nevertheless, it seems on the basis of data furnished by a number of independent investigators that some nitrogen is fixed non-symbiotically. The quantity fixed may not be large.

Fertilizers and manures are also important sources of nitrogen supply. It was estimated by Lipman and Conybeare (op. cit.) that in the United States, in 1930, nitrogen added in the form of fertilizers, animal manures, and green manures was about 0.3 million, 2.5 million, and 0.5 million tons respectively. The use of nitrogen fertilizer has been rising quite

TABLE II. Estimates of Non-symbiotic Nitrogen Fixation

Author(s)	Ref. No.	Location	Crop	Nitrogen fixed, Lb./ac./yr.
Chapman et al.	Op.cit.	California	Wheat straw	48
Gustafson	Op.cit.	England	Grass	36
Hall	Op.cit.	Rothamsted	Gramineous herbage	60
Lyon and Bizzell	96	Ithaca,N.Y.	Barley, rye, or oats	17
Lyon and Wilson	99	Ithaca,N.Y.	Under grass when grass not harvested when grass removed	 32 27
Newton	113	Laboratory experiments		100
Richardson	130	Rothamsted	Grassland	40
Smith	143	Arizona	Wheat and hegari (poor soil) Wheat and hegari (soil rich in nitrogen)	261 48
Smith et al.	145	Texas	Grass sod	20*
Vandecaveye and Villanueva	168	Laboratory experiments		36-1,064
Whitt	184	Missouri	Bluegrass	100
Woodruff	187	Missouri	Corn	20

* Includes nitrogen added through rain.

sharply since then. Collings (37) has reported that in 1950-51 nitrogen consumed in United States of America in the form of fertilizers was about 1.0 million tons. He has also stated that as estimated by the United States Department of Agriculture, the soils of America are enriched to the extent of about 3.0 million tons of plant nutrients by the use of manure.

A number of other ways by which nitrogen is added to the soil have been reported. Allison and Morris (6) have reported that a few genera of blue-green algae are able to fix free nitrogen when grown in pure culture with light as a source of energy. De and Sulaiman (44) and Watanabe et al.(179) have shown that blue-green algae were commonly abundant and were active in nitrogen fixation in rice fields. The quantity of nitrogen fixed by the algae in soil may not be important as conditions for their growth are not favourable except on the soil surface. Lyon et al. (op. cit.) have stated that about 6 pounds of nitrogen fall on every acre of land annually in the form of nitrates and ammonia brought down by rainwater and snow. After making an allowance for the nitrogen which might be lost in runoff, they assumed that about 5 pounds of nitrogen are added to each acre of land every year. Conflicting evidence has been given by different investigators (70, 83) with regard to the addition of nitrogen to soil through adsorption from the atmosphere. It seems that very little, if any, nitrogen is added to soil in this way.

A number of investigators have studied the importance of non-biological nitrogen fixation through photochemical action. Dhar (46) and Dhar et al. (47) have reported comparatively large nitrogen fixation under laboratory conditions, when sterile and non-sterile soil was exposed to light, provided suitable energy sources were available for oxidation. Mitra and Parkash (108) have also reported similar results. Bjalfve (17) found no nitrogen fixation under sterile conditions. He has reported high nitrogen

fixation under non-sterile conditions when straw or starch was added to sand. He also reported that nitrogen fixation was greater in the light than in the dark. However, Burris and Wilson (31) in their review have reported that the work done by some other investigators does not support the claims that non-biological nitrogen fixation is of appreciable importance. They concluded that until more impressive evidence is furnished, the role of non-biological fixation in the soil nitrogen economy should be regarded with considerable reservation.

These investigations on non-biological nitrogen fixation indicate that some nitrogen is added to soil by rain and snow. The quantities of nitrogen added to soil through adsorption of atmospheric ammonia and through photo-oxidation do not appear to be important.

C. Losses of Soil Nitrogen

Nitrogen is lost from the soil in a number of ways. It is lost through the plants grown and removed from the soil, in drainage water, by runoff as organic matter from the surface, and by escape of nitrogen in gaseous form. These losses of nitrogen from the soil as reported by various authors are given in Table III. A number of ways to account for the losses of nitrogen in experiments carried out under controlled conditions in the laboratory, in greenhouse, and in lysimeters have been proposed by several investigators. Some found a large quantity of nitrogen in the leachate. Where there were substantial unaccounted for losses of nitrogen in normal, well aerated soils, they were believed to have been lost through volatilization (12, 26, 48, 66, 67, 78, 171, 185). Pinck et al. (125) found that a considerable portion of the unaccounted for nitrogen was present in the soil combined with carbon. Goring and Clark (64) also concluded that a part of

TABLE III. Estimates of Soil Nitrogen Losses

Author(s)	Ref. No.	Location	N losses -- lb./ac. per annum due to: Harvest	Erosion	Leaching	Volatilization	Remarks
Bizzell	16	Ithaca,N.Y.	91	Nil	46	47	Lysimeter studies using $(NH_4)_2SO_4$ and $NaNO_3$.
Bracken and Greaves	22	Utah	16	Unaccounted for 35 - 45.			Wheat grown for 25-60 years in two valleys under dry land conditions.
Burd and Martin	29	California	50	Lost about 100.			Under both cropped and uncropped systems.
Chapman et al.	Op.cit.	California	Unaccounted for 47.				Lysimeter studies, N was applied at 200 lb./ac. for 10 years.
Collison et al.	Op.cit.	Geneva,N.Y.	44	--	8	11	Lysimeter studies, no fertilizer used on Hill soil.
			69	--	14	46	Lysimeter studies, no fertilizer used on Ontario soil.
			121	--	83	80	Lysimeter studies, 62 lb. N/ac. applied as fertilizer.
Dyer (quoted by Lipman and Blair)	93	Rothamsted	70 believed lost in drainage.				86 lb. N/ac. applied annually for 50 years on a field under cropping.
Lipman and Blair	Op.cit.	New Jersey	78	103 lost in drainage and through volatilization.			Lysimeter studies with 5 year crop rotation, fertilizer, and manure applied.
Lipman and Conybeare	Op.cit.	U. S. A.	25	24	23		Average from the various stations.

TABLE III. Estimates of Soil Nitrogen Losses (Continued)

Author(s)	Ref. No.	Location	N losses -- lb./ac. per annum due to: Harvest	Erosion	Leaching	Volatilization	Remarks
Lyon and Bizzell	97	Cornell	116	in crop and drainage		26	Lysimeter studies, no vegetation for 10 years, cropped for 5 years, no legumes; manure used.
Macintire et al.	100	Tennessee		Unaccounted for 20.			N applied in three forms of ammonium salts, recovery extended over 12 years.
Mann and Barnes	103	Woburn		Unaccounted for 18 to 75.			37 to 150 lb. N/ac. were added in plant material and $(NH_4)_2SO_4$, 2 crops grown for 18 months.
Pinck et al.	125	Maryland	6-81	Unaccounted for 0 to 40.			200 to 800 lb. N/ac. applied in greenhouse studies.
Russell	133	Rothamsted	54	Lost about 123.			F.Y.M. was applied at 200 lb. N/ac. for 47 years.
Shutt	141	Saskatchewan	32	68 lost through erosion and volatilization.			
Snyder	146	Minnesota	25	146 lost through other means.			Wheat was grown continuously.

the added nitrogen was immobilized in the soil. Allison et al. (5) reported that the added nitrogen, especially in ammonia form, might be fixed in the soil in an unavailable and not easily exchangeable form. Stojanovic and Broadbent (155) have reported that the unrecovered nitrogen in ammonia treated soil is attributable to immobilization and in part to chemical fixation. After making allowance for the nitrogen removed in crop, in drainage water, in soil runoff, and by wind erosion, it seems probable that most of the unaccounted for loss of nitrogen from soil occurs through volatilization. A small amount of nitrogen might be either immobilized or fixed on the soil complex.

D. Effect of Cultivation on Soil Nitrogen

A number of investigators have studied the effect of cultivation on the nitrogen content of soil. Schreiner and Brown (op.cit.) found that when land was brought under the plough, there occurred nitrogen losses. The losses were quite high in the early years but later on the nitrogen content was stabilized at a lower level. Similar results were also reported by Newton et al. (115). The data reported by various authors showing the effect of cultivation on the nitrogen status of soils are given in Table IV. These results show that land under cultivation usually undergoes a reduction in its total nitrogen content. The nitrogen losses are usually higher when the land is continuously cropped to grains than when hays and legumes are included in the rotation. However, the data reported by Stewart and Hirst (154), Bradley (24) and Wilsdon and Ali (186) for dry land areas showed almost no loss in nitrogen from cultivated land when compared with similar virgin land. It may be concluded from these investigations that the nitrogen balance in virgin soil is usually adversely affected by cultivation. The rate of nitrogen loss from cultivated land seems to diminish with time, reaching an equilibrium at a lower level.

TABLE IV. Estimates of the Effect of Cultivation on Soil Nitrogen Content

Author(s)	Ref. No.	Location	Original N%	Final N%	Years Cultivated	% N lost	Cropping system
Allison and Sterling	7	North Dakota	.146	.120	33	18	Average of various cropping systems.
Bracken and Greaves	Op.cit.	Utah, 1st foot	.201	.169		16	Cropped dry farm lands.
		2nd and 3rd foot	.107	.091		15	Cropped dry farm lands.
Brown et al.	28	Prairie Provinces, Canada			30	17-22	Grain and fallow.
Caldwell et al.	33	Alberta, Saskatchewan			30	18-35	Wheat 3 to 4 years and then fallow for 1 year.
Danial and Langham	43	Oklahoma	.100	.085		15	
Dodge and Jones	49	Manhattan, Kansas	.168	.140	31	17	16-year rotation, 4-year alfalfa, corn, corn, wheat.
			.158	.129	31	18	3-year rotation, corn, cow-peas, wheat.
			.137	.126	31	8	Continuous wheat.
			.160	.132	31	17	Fertilizer treated.
Harper	76	Oklahoma			15	15	
Hill	81	Lethbridge, Alberta	.199	.163	43	18	Continuous wheat.
			.178	.135	43	24	Alternate wheat and fallow.
			.188	.124	43	34	Wheat, wheat, fallow.
			.168	.140	43	17	6-year rotation including hay.
			.203	.135	43	34	9-year rotation including hay.
			.202	.173	43	15	12-year rotation including hay.

TABLE IV. Estimates of the Effect of Cultivation on Soil Nitrogen Content

Author(s)	Ref. No.	Location	Original N%	Final N%	Years Cultivated	% N lost	Cropping system
Myers et al.	111	Kansas Hays	.220	.125	36	40-45	Various cropping rotations, continuous wheat, wheat-fallow-sorghum.
		Colby	.180	.110	34	40-45	
		Garden City	.121	.025	30	80	
Newton et al.	115	Prairie Provinces, Canada. Brown Zone	.235	.193	16	18	Grain and fallow.
		Dark Brown Zone	.326	.271	22	17	
		Black Zone	.487	.404	26	17	
		Black-transition Zone	.714	.571	24	20	
		Grey-transition Zone	.440	.304	12	31	
		Grey Zone	.190	.120	13	37	
Salter and Green	138	Ohio	.108	.077	31	29	4-year rotation including hay and clover.
			.108	.090	28	17	3-year rotation.
			.108	.042	31	60	Continuous corn.
			.108	.068	31	37	Continuous oats.
			.108	.066	31	39	Continuous wheat.
Shutt	Op.cit.	Saskatchewan	.371	.254	25	30	Grain and fallow.
Sievers and Holtz (quoted by Bracken and Greaves)	Op.cit.	Washington				22	
Snyder	147	Minnesota	.221	.173	8	22	Wheat.
White et al.	180	Pennsylvania	.195	.140	72	28	Grassland vs cultivated.
Woodruff	Op.cit.	Missouri	.170	.070	60	59	Under corn.

E. Need for Using Nitrogen Fertilizer

It has been known for a long time that some soils require nitrogen fertilizers if good crops are to be produced. In recent years, large crop yields have been made possible by better cultural practices and by the introduction of improved high yielding varieties. With high yield, high demand is made on the nitrogen resources of the soil. Stallings (quoted by Parker (119)) has estimated that in 1943 six million tons of nitrogen were removed in the harvested portion of all crops, livestock, and livestock products in the United States. Some of this nitrogen removed in the harvested crops was returned but the net loss must be measured in millions of tons. Pierre (124) reported that in Iowa alone there has been an increase of over two million acres in row crops since 1941. The change in agricultural practices when the area under row crops is increasing also puts a great strain on the nitrogen resources of the soil. The loss of soil nitrogen, by crop removal, in drainage water, in runoff, and due to volatilization needs to be compensated for by the addition of nitrogen. In order to make up for the loss of nitrogen and to meet the nitrogen requirements of the crops, increasing use is being made of nitrogen fertilizers. Use of such fertilizers has increased tremendously during the last twenty years. Parker (op.cit.) states that the worldwide use of nitrogen fertilizer has increased from 0.7 million tons of nitrogen in 1913 to 2.8 million tons in 1937. Collings (op.cit.) has reported that the consumption of nitrogen fertilizer in United States of America has risen from 0.4 million tons in 1940 to 1.1 million tons in 1950-1951. He has also stated that total world consumption of nitrogen fertilizer in 1950-1951 was estimated at 3.9 million tons. Speyer (149) has stated that the total world capacity of industries producing nitrogen for industrial and agricultural consumption increased from 5.5 million

in 1950 to 6.4 million tons in 1953. He estimated nitrogen requirement to be 7.2 million tons by 1956-1957. He has based his estimates on a ten per cent annual increase in the agricultural consumption. The trend indicates that increasing need is being felt for adding nitrogen fertilizer to the soil and its consumption is likely to increase tremendously in the near future.

F. Mineralization of Organic Nitrogen

Plants are thought to obtain their nitrogen requirements from the soil in the form of ammonia or nitrate ions which are taken in through the plant roots (160). Most of the nitrogen in normal soils is present as a constituent of organic matter. In the course of mineralization, nitrogen present in the organic form is converted to ammonia and then to nitrite and nitrate anions. The conversion of organic nitrogen to ammonia has been said to take place in more than one way. Marchal (quoted by Russell and Russell (135)) proposed that in the conversion of organic matter into microbial tissue and energy, ammonia is liberated as a waste product. However, Russell and Hutchinson (134) and Conrad (40) have shown that soils treated with toluene still possess the power to decompose urea and some other amides, presumably by enzyme activity with the production of ammonia and carbon dioxide.

Different mechanisms have been proposed for the conversion of ammonium cations to nitrate anions. Schlosing and Muntz (quoted by Waksman (173)) proved that the conversion of ammonia to nitrate was a biological process. The conversion of ammonia to nitrate takes place in two steps. Winogradsky (quoted by Russell and Russell (135)) isolated the bacterium converting ammonia into nitrite and called it Nitrosomonas. He also isolated the bacterium which further oxidized nitrite to nitrate and termed

it Nitrobacter. Russell and Smith (136) proposed the hypothesis of chemical mineralization of organic matter. They, however, found from their studies that the formation of nitrites or nitrates in the soil from atmospheric nitrogen or ammonia by chemical or physical processes was so small, if any, that it could not be measured. Tandon and Dhar (159) found high accumulation of mineral nitrogen under tropical conditions. They attribute it to the chemical mineralization process induced by the direct irradiation of the soil by sunlight. However, the studies of Fraps and Sterges (56) and of Waksman and Madhok (176) have shown that the photo-chemical nitrification in soil is not important. It is thus well accepted that the mineralization of organic nitrogen is mainly brought about by biological means.

G. Factors Affecting Mineralization

The mineralization of organic nitrogen to ammonia and then to nitrite and nitrate as already indicated is mainly a biological process. In ordinary soils, it has been found that the oxidation of ammonia to nitrite and then to nitrate is so rapid that nitrites and ammonium salts do not ordinarily accumulate. Unlike heterogenous aminizing and ammonifying organisms, the nitrifying bacteria are extremely sensitive to their environment. Factors which influence the rate of nitrification in soil include aeration, temperature, moisture, soil reaction, presence of other nutrients, carbon-nitrogen ratio, etc. Since the effect of some of these factors was studied in preliminary work by the writer, they are briefly reviewed in the following pages. Waksman (174) and Harmsen and Van Schreven (74) have given an extensive review of literature on nitrification in soils.

The effect of aeration on nitrification in soil has been studied by a number of investigators. Nitrification is essentially a process of

oxidation, so aeration is likely to increase the rate of nitrification in the soil. Amer and Bartholomew (8) who studied the relation between the oxygen pressure in the atmosphere and nitrification, found that optimum concentration of oxygen for nitrification in soil was about that contained in ordinary air, that is 20 per cent. Recently, Van Schreven (169) has reported the favourable effect of aeration on the production of mineral nitrogen in both calcareous loam and peat soils. Smith and Cook (144) found that when aeration was poor nitrification was reduced and this lowered the yield of sugar beets. In contrast to this, Van Schreven (170) has reported loss of mineral nitrogen when a soil was excessively aerated by incubation in thin layers. Call and Sewell (34) showed that nitrification is as great in uncultivated silt loam free of weeds as in cultivated soil of the same type. The rate of nitrification seems to depend on the availability of adequate oxygen. Excessive aeration might cause loss of mineral nitrogen.

Several workers have reported the effects of temperature on nitrification. Russell and Russell (op.cit.) have stated that the optimum temperature for nitrification is around 30°C. It is inhibited at low and high temperatures, taking place very slowly below 4°C. or above 40°C. Russell et al. (137) have reported that the optimum temperature for nitrification is 35°C. Similar findings were reported by King and Whitson (87). Tandon and Dhar (op.cit.) reported 35°C. as the optimum temperature for nitrate formers under tropical conditions as against 25°C. observed as optimum in soil of temperate regions. Burns et al. (30) have reported increased nitrification when the temperature increased from 8°C. to 30°C. They observed that at the freezing point there was complete inhibition of nitrification of added $(NH_4)_2SO_4$. They found the oxidation of ammonia was very low in fertilized soils after the soil temperature had decreased below 10°C.

Frederick (60) has reported increased nitrification with temperatures up to 35°C. in an alkaline soil, while in acidic soil the rate decreased after 27°C. He found nitrate formation to increase more particularly between 7°C. and 15°C. than at any other temperature. A temperature between 25°C. and 35°C. seems to be optimum for nitrification.

Moisture effects on nitrification in soil have also been widely studied. Russell et al. (op.cit.) found that a moisture content 1.25 times the moisture equivalent was a little less than optimum. Greaves and Carter (65) found maximum nitrification when soil was at 60 per cent of the maximum water-holding capacity. At higher and lower moistures, it was markedly lower. Gainey (62) working with a silt loam found an increase in nitrification with an increase in moisture up to 66 per cent of saturation capacity. Calder (32) has reported 22 to 23 per cent moisture as most favourable for nitrate accumulation in an Uganda soil. Lees and Quastel (90) have reported that when soils were kept at field capacity the nitrification was not affected adversely. However in their apparatus the water was circulated continuously. Call and Sewell (35) have reviewed the work of various other investigators who had reported nitrification at comparatively low moisture levels under their conditions. The moisture content of 60 to 70 per cent of field capacity seems to be optimum for nitrification.

The question of optimum pH for nitrification has been studied by various investigators. Martin et al. (104) found pH 7.6 $\pm$ .1 as an upper limit for nitrification in alkaline desert soils. Halvorson and Caldwell (71) concluded that in Floyd soils, low pH might have been the limiting factor in nitrate production. The addition of $CaCO_3$ increased the rate of nitrification. Similar results were reported by Fraps and Sterges (57), Bear (14), and Collins (38). The presence of free $CaCO_3$ has been reported to be toxic by Brown and Hitchcock (27) and by Halvorson and Caldwell. Stevenson and Chase (152) found the addition of lime increased the nitrifying capacity of acid orchard soil. They attributed it either to the stimulation effect of

$CaCO_3$ or to the increase in soil pH. Harper and Boatman (77) obtained good agreement between the soil reaction and its nitrifying power when ammonium sulphate was added to the soils and they were incubated. The optimum pH for nitrification is near neutral reaction, high and low pH values affect nitrification adversely.

That addition of plant nutrients has an effect on nitrification was verified by certain investigators. Harper and Boatman (op.cit.) in field experiments and Halvorson and Caldwell (op.cit.) in laboratory studies did not find any significant increase in rate of nitrification due to the addition of phosphate and potash. Baldwin et al. (11), Yankovitch and Yankovitch (189), Whiting and Schoonover (183), and Fraps and Sterges (58) have reported beneficial effects from phosphates. Baldwin et al. reported the beneficial effect of potash and water soluble nitrogen as well. Whiting (182) concluded that the water soluble nitrogen content of the organic material determines to a large extent the rate of nitrification in the initial periods. Stojanovic and Broadbent (op.cit.) have also reported that mineralization of organic nitrogen was enhanced by the addition of inorganic nitrogen. Collins (op.cit.) has reported that maximum nitrification occurred when trace elements were added along with $CaCO_3$ and phosphorus to the soil. Nitrification rate seems to be enhanced if any essential element which the soil lacks is added.

Different views have been expressed by various investigators concerning the effects of total nitrogen on nitrification. Fraps (55) and Allison and Sterling (op.cit.) have reported that nitrification in the soil is related to the total nitrogen content. Fraps found a relationship between the nitrogen content of the soil and the amount of nitrogen removed in the crop. He also observed a correlation between the nitrogen removed

by the first crop and the amount of available nitrogen. Allison and Sterling found that nitrate formation from soil organic matter was directly correlated with total soil nitrogen. They concluded that in given soil type and under like climatic conditions, thoroughly humified soil organic matter is uniform in quality regardless of past agronomic practices. Gainey (63) and Acharya and Jain (1) have reported very slight or even no correlation between nitrogen content of the soil and nitrate formed. Gainey argued that so long as the nitrogen present in the soil organic matter varies in its nitrification ability, it is not possible to have a high correlation between the two. Similar views were expressed by Crowther and Mirchandani (42). It seems that the rate of nitrification may be proportional to the soil nitrogen if the latter is present in organic forms which are similar in nature.

There have been many studies on the effect of carbon-nitrogen ratios on the mineralization of the organic substances applied as a manure to soil. Rubins and Bear (132) found that washed organic materials which contained three per cent or more nitrogen rated comparatively high in nitrogen availability whereas those containing lesser percentages ranked low. Bould (20) found that refuse composts with nitrogen content greater than three per cent would liberate nitrogen on decomposition. He has also reported that Waksman as well as Hutchinson and Richards gave a figure of two per cent as the nitrogen content below which organic matter will usually not liberate available nitrogen immediately when added to the soil. Barnes (13) found that the addition of straw depressed the formation of nitrates for 89 weeks, while a part of the added nitrogen in the form of ground mustard plant material (1.49 per cent nitrogen) and ground tare (3.46 per cent nitrogen) changed to nitrates in eleven weeks under the same conditions. Patrick (120) compared the effect of timothy, red clover, and maize residues on the nitrate content of the soil. He found greatest depression of nitrification with timothy and the least with

maize. He attributed the lower depression in nitrification by maize to its low percentage of easily decomposable soluble organic matter and its narrow carbon-nitrogen ratio. Millar et al. (106) showed that the accumulation of nitrates in the soil was depressed to a greater extent with material having a relatively wide carbon-nitrogen ratio than with material having a narrow carbon-nitrogen ratio. These studies indicate that organic materials containing less than 2 to 3 per cent nitrogen, that is with high carbon-nitrogen ratios, do not ordinarily liberate available nitrogen for some months after their addition to soil.

The quality of organic nitrogen as well as the quantity and quality of organic carbon present have been found to affect the availability of nitrogen. Whiting (op.cit.) has reported that in case the nitrogen is present in resistant form, in spite of a low carbon-nitrogen ratio, the availability of nitrogen will be low. On the other hand, if the carbon present is in a more resistant form than the insoluble nitrogenous compounds, the availability of nitrogen will be comparatively greater in spite of the high carbon-nitrogen ratio. Rubins and Bear (op.cit.) have also reported similar findings. They concluded that the insoluble nitrogen of processed tankage and bonemeal was of poor availability not because of unfavourable carbon-nitrogen ratio, but because of the resistance to decomposition of these nitrogen-containing compounds. Newton (114) and Hedlin (79) have reported higher nitrate accumulation in peat, and in a peat-soil mixture than in black soil. The carbon-nitrogen ratio in this peat is near 20 whereas a mineral soil has a ratio of 10 to 12. Lyon et al. (op.cit.) have stated that higher nitrification in peat may be explained on the basis of large amounts of nitrogen (2.5%) being carried in the peat and the inactivity of part of the carbon present. Newton as well as Norman (117) have also given similar reasoning for the higher nitrification in peat than in mineral soil.

Broadbent and Norman (25) have reported that the unavailability of organic nitrogen to crops may possibly be due to a relatively low level of microbial activity which is reached when the readily available energy sources become depleted. In the presence of organic material rich in nitrogen, the release of nitrogen from the previously formed residues is apparently accelerated. These findings indicate that mineralization of organic matter depends upon the availability of energy and the ease with which nitrogenous compound may be decomposed.

The effects of straw and other crop residues on the availability of nitrogen have been reported by certain investigators. Murray (110) found that the addition of straw reduced the accumulation of nitrates. He offered a number of explanations for the deterimental effect of straw. The addition of cellulose may have a toxic effect on the nitrifying bacteria. It may be that the cellulose-fermenting organisms use up the nitrates as their food and thus lower the available nitrogen content of the soil. Another suggestion is that straw acts as a source of energy to a host of soil organisms which then use the nitrogen available in the soil for their own purposes. The adverse effect of straw on the nitrogen nutrition of plants have also been reported by Richards and Norman (129) and Leferve et al. (91). Newton et al. (116) studied nitrification rate in fields after growing alfalfa, brome, timothy, and western rye grass. They found that nitrate content of the alfalfa plot soils was generally greater than that of the grass plots, and brome grass plots were generally lower in nitrates than the timothy and western rye grass plots. Hedlin et al. (80) have also reported that yields of wheat following alfalfa, grass and straw were in descending order. Ellis (53) has also reported similar results. These findings indicate that plant residues with a wide carbon-nitrogen ratio left in the soil, or added as cereal straw, decrease the rate of

nitrification comparatively more than the plant residues with a lower carbon-nitrogen ratio. The soil microorganisms seem to immobilize nitrogen while decomposing residues with high carbon-nitrogen ratios.

The effect of the addition of nitrogen on the carbon content of the soil has been reported by some investigators. Millar et al. (107), Turk and Millar (163) have suggested a beneficial effect of high nitrogen content on carbon build-up by bringing about humus synthesis. Newton (113) has also suggested that the addition of nitrogen is essential in the maintenance of organic matter content of cultivated soils as the humified organic matter has a fairly definite ratio of carbon to nitrogen. However, Peevy and Norman (123) could not demonstrate any appreciable effect of nitrogen on the maintenance of carbon. Pinck et al. (126) concluded that the loss of carbon is rather accelerated during the first few weeks of the addition of available nitrogen to nitrogen-deficient material. They considered that the acceleration in loss of carbon might be due to the stimulating effect of available nitrogen on the soil organisms. They claimed that the carbon retention in certain materials was not due to humus formation on account of high nitrogen content but was the result of the composition of plant material itself. In view of these conflicting views, it seems the importance of adding nitrogen to bring about humus formation and thus conserve organic carbon has not been definitely established.

H. Methods of Determining the Need for Nitrogen Fertilization

A crop is fertilized to supply required nutrients which are not available in adequate amounts from the soil. It is difficult to determine the requirements of various crops under different soil and climatic conditions. The problem is further complicated by the economics of fertilizer use. It is quite possible to add sufficient quantity of a nutrient in the form of fertilizer to ensure that it is not a limiting factor in crop growth. But,

with the increase in the amount of fertilizer applied, there may not be a proportional increase in yield and a point may be reached when the extra supply may be taken up by the plant extravagantly or it may be lost from the soil through erosion, leaching, and in the case of nitrogen fertilizers by denitrification.

It has been a constant endeavour of soil and plant workers to find ways of evaluating the requirements of different crops under different sets of soil and climatic conditions. The field trial is the oldest of the various methods developed for evaluating a new cultural practice and it is still considered to be the most reliable. But, the main objection to its wide adoption has been its high cost as well as the long time taken to complete a test. Besides, the results obtained apply only to the place where the field experiment has been conducted. For different types of soils, different results might be expected. Other methods, for example soil and plant analyses, have been tested widely. They have their appeal in lower costs, the possibility of taking less time, and the hope of having wider applicability.

In the determination of the fertilizer needs of soil, nitrogen causes the most difficulty. Almost the total stock of this element in the soil is bound up with organic substances either in stabilized humus or in the still undecomposed particles of vegetable or animal origin. In these organic forms, nitrogen occurs in proteins and protein-like compounds. By the action of soil microorganisms, small amounts of this protein nitrogen are continually transformed to inorganic forms. The nitrogen is unavailable to the plants before this transformation. It therefore seems futile to determine total nitrogen content of soils and then base fertilizer recommendation on this, when most of it is in unavailable form. However, Jenny (85) reported almost a perfect correlation between the average yield of corn per acre and the average total nitrogen content of the soils in certain parts of United

States of America. White et al. (181) have also reported a high correlation between total nitrogen content of soils and the crop yields. As previously indicated, the availability of soil nitrogen is dependent not only on the nitrogen content of the soil but also on the form in which organic nitrogen is present. It also depends on the nature and quantity of the organic carbon which accompanies the organic nitrogen. In view of these facts it is questionable if the determination of total nitrogen in soil could be used for determining the fertilizer requirements for different crops.

In view of the doubtful value of total nitrogen determination for ascertaining fertilizer requirements, the question then arises whether the determination of available nitrogen in ammoniacal and nitrate forms can be usefully employed in predicting nitrogen fertilizer requirements. Again the answer would be negative. The amount of available nitrogen in the form of ammonia and nitrates at any time represents an accumulation as a result of mineralization of organic matter. This accumulation occurs when there are conditions favourable for it, when there is no net leaching, and when the land is not under a crop. In a temperate climate, the temperature in winter and early spring is too low for the active functioning of the microorganisms responsible for the conversions involved. Shortly before sowing a crop in late spring, there is the possibility of small amounts of organic nitrogen being converted to available mineral form. When the crop starts growing, it may soon exhaust the supply of available nitrogen and for the rest of its growth the crop depends upon the nitrogen liberated by microorganisms from the humus. Thus, the determination of available nitrate nitrogen present in a soil is of little use in determining the need for nitrogen fertilization.

Several rather different types of procedures have been proposed as a means of determining the need for nitrogen fertilization. Pritchett

et al. (127), Harmsen and Lindenberg (73), and Harmsen and Van Schreven (op.cit.) have reviewed some of these methods. Plant yields and their composition have been determined by some investigators. Mitscherlich (quoted by Stewart (153)) grew plants in pots with increasing increments of nitrogen and from their yield determined the nitrogen available in the soil. Macy (101) found that the nitrogen content of plants was correlated with yield. He has proposed, therefore, that the nitrogen requirements of crops could be estimated by determining the nitrogen content of plants. Lundegardh (95) and Dulac (52) have reported that the percentage of nitrogen in leaves collected at the flowering stage correlated with the yield. Ulrich (166) and Ririe et al. (131) advocated the determination of nitrate present in the plant in the early stages of its growth for estimating the nitrogen requirements of crops. Magnitsku (102) has also reported that the chemical analysis of plant tissues could be used to determine nitrogen requirements. Thus, plant yield and composition have been successfully used for evaluating nitrogen requirements of soils by certain investigators.

Other researchers have used chemical methods to find out the quantity of organic nitrogen likely to become available to the growing crops. Tyurin (164) proposed that acid hydrolysis serves to distinguish organic matter decomposable by microorganisms from that which is stable in that respect. Tyurin and Kononove (165) treated the soil with 0.5 N. H_2SO_4 at room temperature. If the total nitrogen determined on the extract was found to be below 60.0 mg. per kgm. of soil, the soil was classified to be deficient in nitrogen. Truog et al. (162) have also reported that the release of ammonia, when a soil samples is boiled for five minutes with potassium permanganate and anhydrous sodium carbonate, can be used in estimating the nitrogen fertilizer requirements of corn and small grain

crops under Wisconsin conditions. The method will be referred to as the Wisconsin method hereafter. These chemical methods seem to offer the possibilities of wide adaptation because they are quick and simple.

The rate of accumulation of nitrates in the soil, when incubated under optimum conditions of temperature and moisture for a given length of time, has been used as a criterion for determining the nitrogen-supplying power of soil by several investigators. Waksman (175) has reviewed the work of a number of early workers who observed a definite relationship between the nitrifying capacity and the crop-producing power of a soil. Varallyay (172) also found this method quite satisfactory for estimating the fertilizer requirements of soils. Black et al. (18), Pritchett et al. (op.cit.), and Cook et al. (41) have reported a significant relationship between nitrate accumulation in soil and their nitrogen-supplying power for certain small grain crops. Richardson (op.cit.) found that a relationship exists between mineralizable nitrogen and the nitrogen content of the non-leguminous herbage. He also reported that they had found a relationship between nitrogen response in field experiments and mineral nitrogen in incubated soils. White et al. (181) have reported a highly significant correlation between crop yields and nitrifying capacity of soils. Allison and Sterling (op.cit.) also concluded that nitrification studies if conducted under optimum conditions would furnish information on nitrogen availability. Hanway and Dumenil (72) found a significant correlation between nitrification rate and the response of corn to the application of 40 and 60 pounds of nitrogen per acre. Saunder et al. (139) found a highly significant correlation between nitrate accumulation and yield from plots unfertilized with nitrogen but supplied with phosphorus and potash. Lenhard (92) has also claimed that nitrate accumulation in soils leached with saturated $CaSO_4$ solution gave values

which provide a fair estimate of the nitrogen-supplying power of a soil. In certain cases the correlation between nitrifying capacity and the response of the soil to nitrogen fertilizer has been questioned. Jeffries (84) found a poor correlation between nitrate accumulation and the crop yield on plots which had incomplete treatments. He attributed this to the limiting effect of other factors which have a controlling influence on crop production. Allen and Bonazzi (2) found that nitrifying capacity of a soil may or may not correlate with its crop-producing power. Joshi and Joshi (86) also questioned the importance of nitrification as an index of soil productivity. The nitrifying capacity of soils with a few exceptions seems to be quite a useful test for determining the nitrogen requirements of soils.

A few other methods for determining the nitrogen requirements of soils have been studied and proposed by other investigators. Dean (45) has described the 'a' value as a measure of the available phosphorus in a soil. This value is obtained by determining the total uptake of phosphorus by plants at several rates of applied phosphorus. When these uptake values are plotted against the rates of phosphorus applied, a somewhat linear relationship is found. A linear regression equation depicting this relationship can be calculated for the soil. On extrapolating the regression line back to the x-axis, a value which Dean termed as 'a' value is obtained. This value is in the same units and form in which the fertilizer is added. In a similar manner Munson and Stanford (109) have determined 'N' values for nitrogen which correspond to Dean's 'a' values for phosphorus. They found a high correlation when 'N' values were related to yield, nitrate accumulation, and nitrogen uptake from soils untreated with nitrogen.

Swaby (157) has reported that by comparing the respiration curves in the presence and absence of each essential element, the degree of

its deficiency can be assessed. He has reported that the method can detect deficiencies of nitrogen. Andrews (9) has stated that the production of carbon dioxide in soils to which mannite has been added under controlled laboratory conditions furnishes a basis for measuring the nitrogen requirements of soils. Woodruff (op.cit.) and Smith (142) estimated the nitrogen requirements of crops by finding the rate at which nitrogen is delivered to crops from the organic matter supplies of the soil. Smith suggested the per cent of total nitrogen, released during the summer under Missouri conditions was 1.5 to 3 per cent for silt loams, 1.25 to 2.5 per cent for clays and clay loams, 4 to 6 per cent for sands and sandy loams. The amounts released under small grains during the winter were considered to be approximately one-half of these quantities. Based on these calculations, he found a good correlation between crop responses and the soil treatments with nitrogen. Kresge and Merkle (89) have, however, reported that the value of any blanket figures such as two, three, or four per cent of the total soil nitrogen as representing the seasonal delivery capability is far from being useful. These methods are in fact measures of the mineralizing capacity of organic nitrogen present in the soil. The actual determination of nitrate accumulation is not done so their value in assessing the nitrogen requirements of the soils is likely to be poorer than nitrifying capacity of the soils.

In general, it may be stated that of all the tests the nitrate accumulation test seems to be the best in evaluating the nitrogen-supplying power of the soils for different crops. The method is quite simple and does not require any special equipment. The Wisconsin method also seems to have its merits in being quick and simple. The main stress was therefore laid on the nitrification test in subsequent studies. The Wisconsin method and a few other tests were also included in the study.

PRELIMINARY STUDIES ON NITRIFICATION WITH FOUR SOILS

A. Purpose of Study

The review of literature concerning the estimation of nitrogen-supplying power of soils indicated that of the different methods used, the nitrification test seems to be the most satisfactory. It was, therefore, decided to carry out some preliminary work on nitrification using Alberta soils. Four soils, for which field response data to the application of fertilizer nitrogen were available, were selected for the purpose. Data concerning these soils are given in Table V. The chief aim of the study was to find the relationship of nitrate accumulation in these soils to their response to nitrogen fertilization in the field. These preliminary studies were also intended to obtain information regarding the following:

1. The effect on nitrification when soil is leached with distilled water prior to incubation.
2. The effect of a complete nutrient solution minus nitrogen on the rate of nitrification.
3. The comparative rates of nitrification at 15°C., 28°C., and 35°C.
4. The comparative nitrate accumulation after two, four, and six weeks of incubation.
5. The effect of vermiculite addition on the rate of nitrification.
6. The optimum moisture level for nitrification.
7. The comparative rates of nitrate accumulation and carbon dioxide evolution.
8. The determination of nitrate accumulation by the Iowa method.

B. Materials and Methods

Details of procedures for preparing soil samples, and for

TABLE V. Some Data Concerning the Four Soils Used in Preliminary Studies

Soil No.	Legal Location	Soil Zone	Soil Series	Experimental Crop in 1955	Check Yield Bu./Ac.	Yield Increase with N/Ac. 33 lb.	67 lb.	No. of Crops since fallow	No. of years cultivated	Straw Cover	Previous Crop
1*	NE 8-16-25-4	Dr.Br.	Shallow Lethbridge loam	Wheat	25.4	4.3	13.5	1	40	Medium	Wheat
2*	SW 23-52- 3-5	Deg.Bl.	Winterburn loam	Wheat	13.7	2.7 with - 19 lb.N/Ac.		Nil	40	Light	Fallow
3*	NE 7-54-22-4	Black	Malmo SiC loam	Barley	30.1	4.4	0.2	1	50 **	Heavy	Barley
4*	NW 36-50-25-4	Black	Ponoka loam	Oats	20.8	21.3	26.2	1	50	Medium	Wheat

* Name and address of farmer:
Soil No. 1, Galbraith, Vulcan; Soil No. 2, Tyrell, Duffield; Soil No. 3, Galloway, Ft. Saskatchewan;
Soil No. 4, Lother, Nisku.

** Approximate, exact information not available.

laboratory analyses used in the preliminary studies are given below.

1. Preparation of the soil samples.

   The air-dried soils were crushed in a crushing machine until they passed a 2 mm. sieve. The sieved soils were thoroughly mixed and were then quartered to obtain sub-samples for laboratory use. In order to prepare leached soils samples, about 200 gm. at a time were placed in Buchner funnels and leached with three 300 ml. portions of distilled water. About 4,000 gm. of each soil were thus leached. They were thinly spread out for quick air drying. Dried soils were again passed through the soil crusher and sieved through a 2 mm. sieve.

2. Optimum moisture content.

   According to the established practice in the Department of Soil Science, it was decided to incubate soils at a moisture content which was 50 per cent of the field or water-holding capacity. In order to determine field capacities, 50 gm. of the soils were placed in large funnels having moist, loose glasswool plugs. The soils were moistened once or twice until thoroughly wet and the amount of water retained, after 45 to 60 minutes standing, was measured. The water-holding capacity of vermiculite was also determined in the same manner. The water-holding capacities of the four soils, No. 1, 2, 3, 4, and vermiculite per 100 gm. were 54, 54, 75, 52, and 523 ml., respectively.

3. Nitrate was determined by the phenoldisulphonic acid method (75). Details are given in the Appendix 1.

4. In order to determine the rate of carbon dioxide evolution, 250 gm. of soil alone or soil mixed with an equal volume of ground vermiculite were placed in a quart sealer and water was added to 50 per cent of field capacity. The soil and water were thoroughly mixed. A 4-ounce open-mouthed jar containing 20 ml. of 0.5 N. NaOH was placed in each sealer.

The jar rested on a glass triangle in the sealer and the sealer was closed. After a specified period, the four-ounce jar was removed from the sealer and the carbonate formed was precipitated by adding about one-half gm. of $BaCl_2$. The amount of NaOH which remained unchanged was determined by titration against 0.5 N. HCl using phenolthalein indicator. Blanks in duplicates without soil were also run with each set. From the quantity of NaOH converted to carbonate, the amount of carbon dioxide evolved was calculated. This procedure has been used in this laboratory for many years.

5. Incubation for determining the rate of nitrification was done on a 50-gm. soil sample. The soil sample (plus an approximately equal volume of ground vermiculite where applicable) was placed in an eight-ounce jar, water or nutrient solution as the case may be was added to 50 per cent of field capacity. In cases where vermiculite was mixed with the soil and the effect of nutrient solution was being examined, water was used to moisten the vermiculite and nutrient solution was used for the soil. After thorough mixing, the jar was covered with a lid perforated with one 3 mm. diameter hole. In order to maintain the moisture level, the jar was weighed weekly and the loss of moisture was made up. The soil samples without vermiculite additions were stirred weekly. At the end of the incubation period, the nitrate which had accumulated was extracted and determined.

6. The nutrient solution used had the following composition:

Nutrient Salt	Gm. per 18 Liters of Water
$Ca(H_2PO_4)_2 \cdot H_2O$	3.2
$CaCl_2 \cdot 2H_2O$	4.7
$MgSO_4 \cdot 7H_2O$	5.5
K_2SO_4	4.0

$FeSO_4$ solution was prepared separately by dissolving 0.5 gm. in 250 ml.

of water. Three drops of this solution were added along with the other solution to the soil sample.

C. Results and Discussion

a. Nitrate accumulation under different treatments and its relation to field yields

Nitrate accumulations under different treatments when the soils were incubated at 28°C. for three periods are given in Table VI. These results indicate the following:

1. The addition of vermiculite to the soil increases the rate of nitrification. It is likely that vermiculite helps in the aeration of the soil and thus increases the activity of the aerobic nitrifiers.
2. Nitrate production increases with time of incubation. The rate of nitrification was higher when the soils were leached with the exception of soil No. 2.
3. In almost all cases, the addition of nutrient solution instead of water to the leached soils resulted in a somewhat lower rate of nitrification; in half the cases it was quite evident. It is probable that the nutrient solution results in a disproportionate increase in the number of heterogenous microorganisms. These organisms probably obtain their nitrogen requirements by drawing on the nitrates formed. If this is so, the consumption of the nitrate formed by these microorganisms may be compared to straw induced nitrogen deficiency in farm fields.
4. Table VII showing the general relationship of fertilizer response and nitrate accumulation in leached and unleached soils indicates that the two seem to be negatively related.

TABLE VI. Nitrate-Nitrogen Accumulation in the Four Soils Incubated at 28°C.

Soil No.	Treatment	NO_3 - N p.p.m. originally present*	NO_3 - N p.p.m. accumulation after incubation for* 2 weeks	4 weeks	6 weeks
1.	Without vermiculite				
	(a) Unleached	30	30**	52	60
	(b) Leached	1	44	70	80
	(c) Leached & nutrients	1	46	68	79
	With vermiculite				
	(a) Unleached	30	35	60	78
	(b) Leached	1	58	76	95
	(c) Leached & nutrients	1	53	73	87
2.	Without vermiculite				
	(a) Unleached	8	53	118	130
	(b) Leached	Trace	39	112	124
	(c) Leached & nutrients	Trace	29	93	121
3.	Without vermiculite				
	(a) Unleached	22	48	68	73
	(b) Leached	2	65	83	92
	(c) Leached & nutrients	2	63	78	89
	With vermiculite				
	(a) Unleached	22	54	82	93
	(b) Leached	2	80	107	119
	(c) Leached & nutrients	2	72	97	110
4.	Without vermiculite				
	(a) Unleached	8	31	44	55
	(b) Leached	1	64	75	85
	(c) Leached & nutrients	1	54	61	72

* These values are averages of duplicates and are on an air-dry basis. In this and in subsequent tables the maximum difference between duplicate was 2.0 p.p.m.

** These figures represent increase in NO_3 - N over and above amounts initially present.

TABLE VII. Comparison Between Nitrate-Nitrogen Accumulation in the Four Soils and Their Responses to Nitrogen Fertilizer

Soil No.	NO_3 - N. p.p.m. accumulation in 4 weeks at 28°C.* Unleached	Leached	Field response to N
1	52**	70	Fair
2	118	112	Nil
3	68	83	Slight
4	45	75	Good

* These values are averages of duplicates and are on an air-dry basis.

** These figures represent increase in NO_3 - N over and above amounts initially present.

In view of some relationship between rate of nitrate accumulation at 28°C. and crop response, it was decided to determine the nitrification at 15°C. which approximates field conditions. The treatments used and the data obtained are given in Table VIII. The data confirmed the findings of the preceding experiment. In soil No. 4, the addition of vermiculite depressed the nitrate accumulation which might be due to denitrification accelerated by excessive aeration in this light textured soil (170).

In order to determine the effect of different moisture levels on the rate of nitrification, Soil No. 1 and 3 mixed with vermiculite were incubated at 40, 50, and 60 per cent of field capacity. Incubation temperature was 35°C. and the chamber atmosphere was kept saturated with water. Other details were the same as in preceding experiments. The data obtained are given in Table IX. These results show little difference between nitrate accumulation at 50 and 60 per cent moisture level. It is slightly lower at 40 per cent of field capacity. The data also show that for these soils nitrate accumulation when incubated at 35°C. for 3 weeks is approximately equivalent to 6 weeks incubation at 28°C.

TABLE VIII. Nitrate-Nitrogen Accumulation in the Four Soils Incubated at 15°C.

Soil No.	Treatment	NO_3 - N. p.p.m. originally present*	NO_3 - N. p.p.m. accumulation after incubation for:* 2 weeks	4 weeks	6 weeks
1.	With vermiculite				
	(a) Unleached	30	23**	33	41
	(b) Leached	1	47	59	64
	Without vermiculite				
	(a) Unleached	30	--	25	--
	(b) Leached	1	--	54	--
2.	With vermiculite				
	(a) Unleached	8	20	82	103
	(b) Leached	Trace	16	74	108
	Without vermiculite				
	(a) Unleached	8	--	67	--
	(b) Leached	Trace	--	54	--
3.	With vermiculite				
	(a) Unleached	22	42	52	54
	(b) Leached	2	68	82	90
	Without vermiculite				
	(a) Unleached	22	--	46	--
	(b) Leached	2	--	79	--
4.	With vermiculite				
	(a) Unleached	8	13	17	23
	(b) Leached	1	15	19	26
	Without vermiculite				
	(a) Unleached	8	--	27	--
	(b) Leached	1	--	41	--

* The values are averages of duplicates and are on an air-dry basis.

** The figures represent increase in NO_3 - N over and above amounts initially present.

TABLE IX. Effect of Moisture on Nitrate-Nitrogen Production in Two Soils

Soil No.	Treatment	NO_3 - N p.p.m. production when incubated at 35°C. for:* 0 weeks	3 weeks	6 weeks
1.	Unleached soil mixed with vermiculite at:			
	(a) 40% field capacity	30	109	134
	(b) 50% field capacity	30	116	141
	(c) 60% field capacity	30	113	143
3.	Unleached soil mixed with vermiculite at:			
	(a) 40% field capacity	22	116	157
	(b) 50% field capacity	22	129	169
	(c) 60% field capacity	22	135	166

* These values are averages of duplicates and are on an air-dry basis.

b. Relationship of nitrification to CO_2 evolution

As carbon dioxide evolution is easier to measure than nitrate accumulation, it was decided to determine whether there is a close relationship between the two values. The previously described procedures for measurement of carbon dioxide and incubation were used. The incubation temperatures were 28°C. and 35°C. The results obtained are presented in Figures 1 to 4. It will be observed that based on the data of these four soils, there is a close relationship between carbon dioxide evolution and nitrate accumulation, with a few noticeable variations in some soils. The results of nitrate accumulations at two temperatures indicate much higher nitrate accumulation at 35°C. than at 28°C. The effect of leaching on

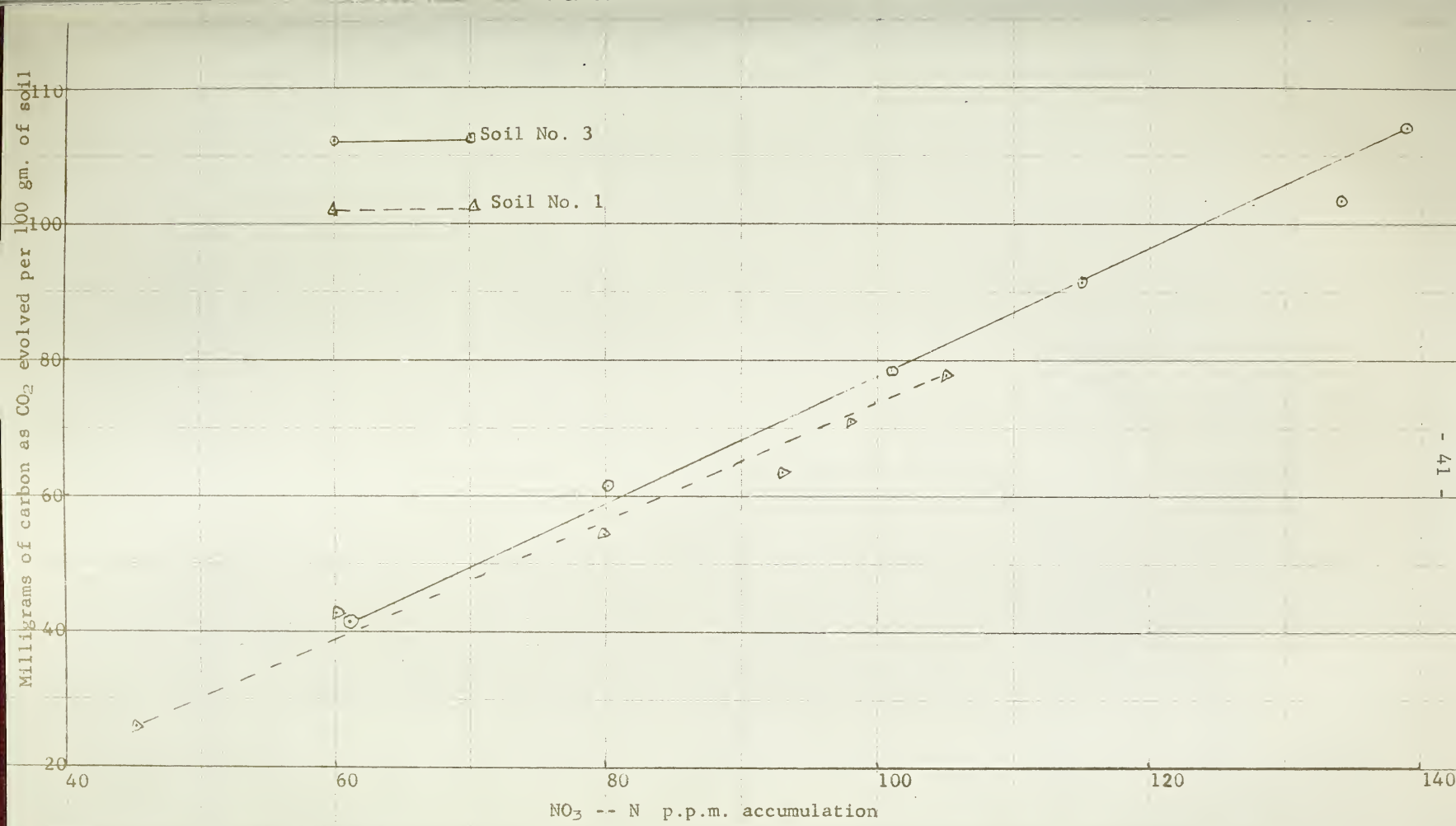

FIGURE 1. Relationship between CO_2 evolution and nitrate-nitrogen accumulation for two unleached soils mixed with vermiculite and incubated at 35°C. for 6 weeks.

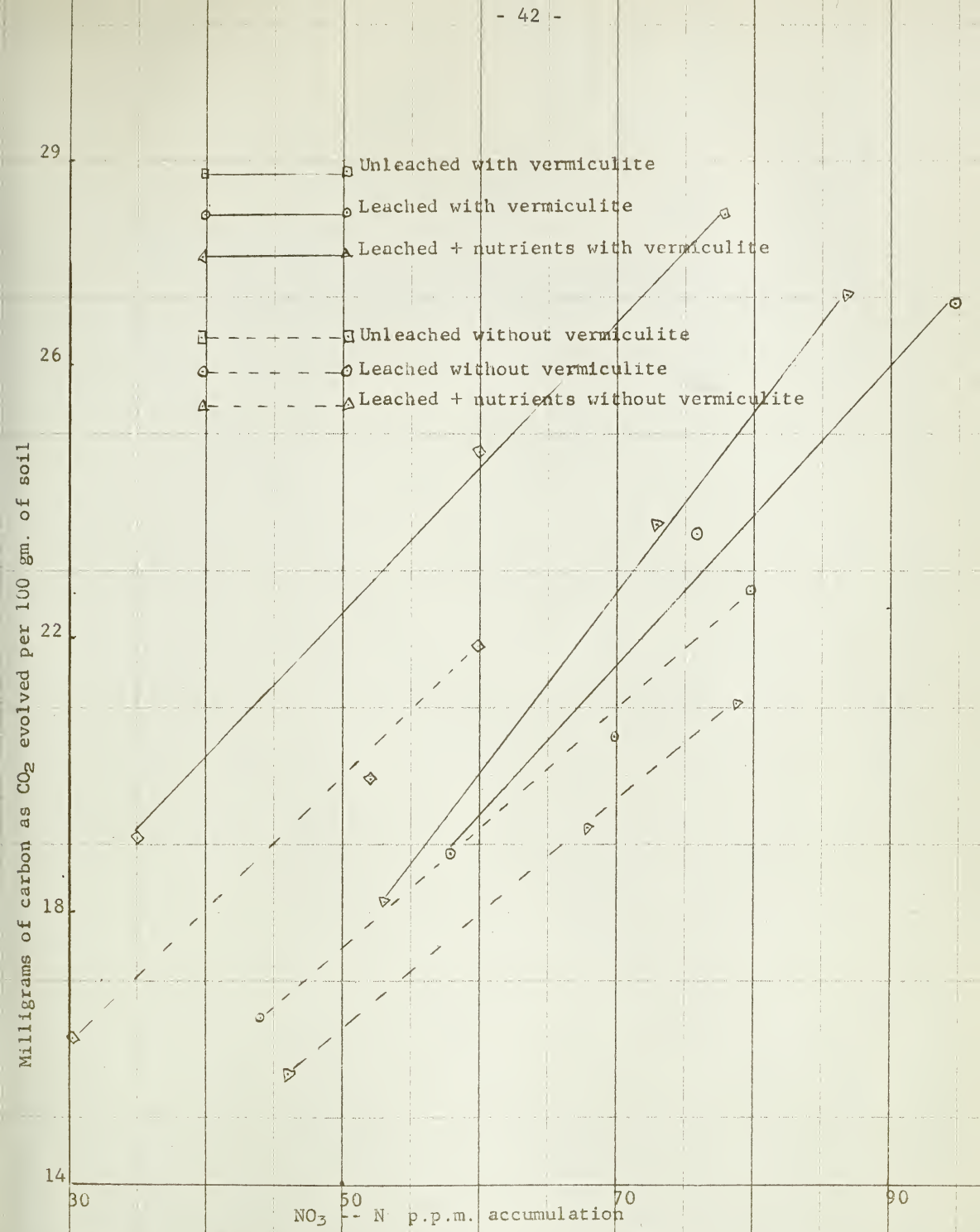

FIGURE 2. Relationships between CO_2 evolution and nitrate-nitrogen accumulation in soil No. 1 incubated at 28°C.

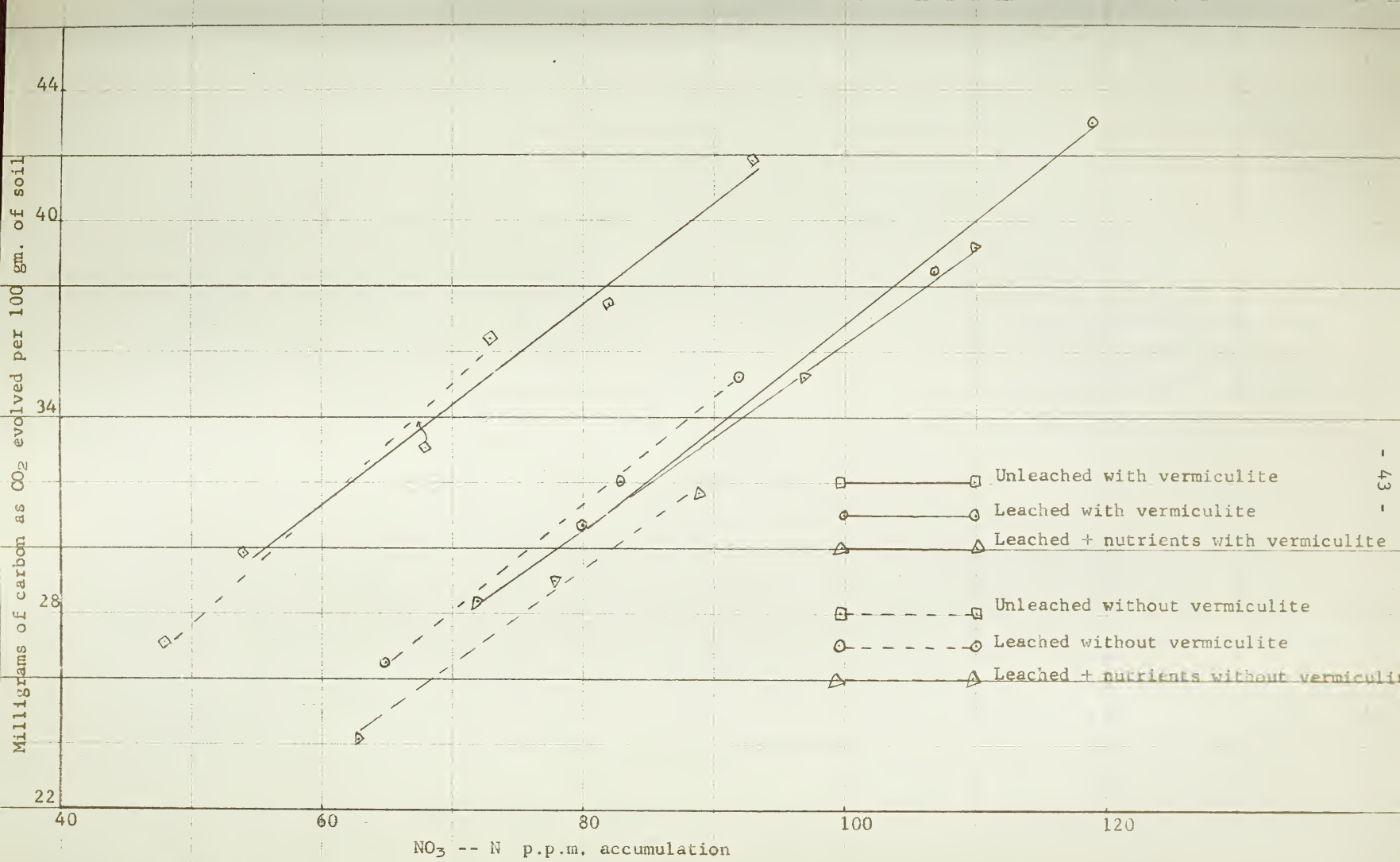

FIGURE 3. Relationships between CO_2 evolution and nitrate-nitrogen accumulation in soil No. 3 incubated at 28°C.

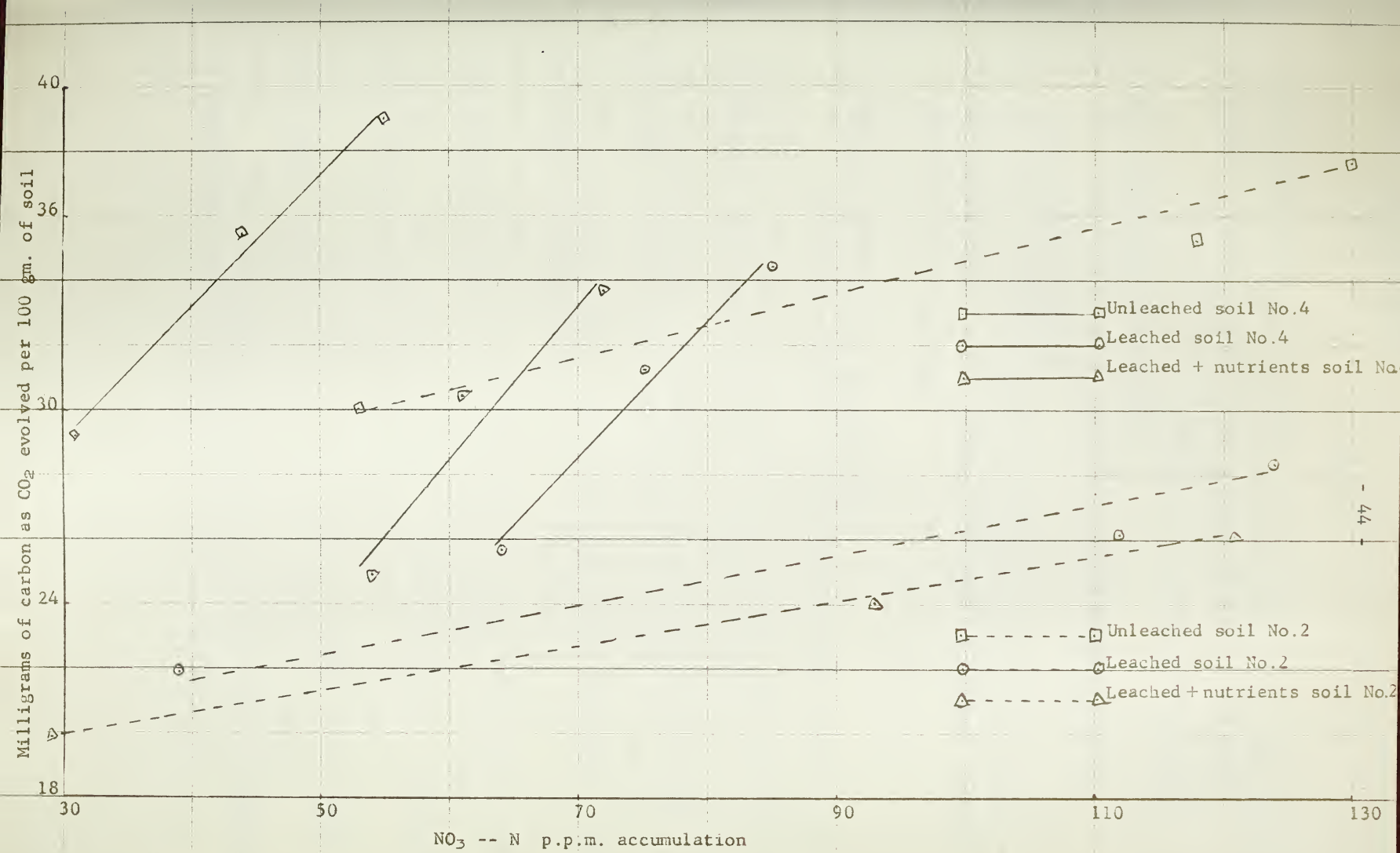

FIGURE 4. Relationships between CO_2 evolution and nitrate-nitrogen accumulation in two soils incubated at 28°C.

carbon dioxide production was variable with different soils. The addition of a nutrient solution depressed carbon dioxide evolution in all cases.

It was decided to discontinue the determination of carbon dioxide for the following reasons:

1. There were certain variations between nitrate accumulation and carbon dioxide evolution.
2. The numbers of carbon dioxide determinations required were numerous.
3. The determination of carbon dioxide evolution is an indirect approach which may not be justifiable.

c. Nitrate accumulation by the Iowa method

At Iowa State College a simple method has been devised by Fitts et al. (54) to study the nitrifying power of the soils. This procedure will be called the Iowa method hereafter. The method was developed while studying the relationship of nitrification to nitrogen fertilization in Iowa. An attempt was made to use the Iowa method on the Alberta soils selected in these preliminary studies. The method which has been described in detail by Stanford and Hanway (150) was followed very carefully. After treating the soils according to the procedure, the carbon tubes containing the soils were incubated at 35°C. for two weeks. During incubation, the chamber atmosphere was kept saturated with water. Following incubation, the nitrates were removed by leaching with three successive 20 ml. increments of distilled water, using suction of 9 to 10 pounds per square inch to remove water between successive treatments. The data obtained are given in Table X. These results show that the procedure followed gave poor duplication as compared with nitrate accumulation determined by incubations in jars.

TABLE X. Nitrate-Nitrogen Production in Four Soils by the Iowa Method

Soil No.	NO_3 - N p.p.m. production when incubated at 35°C. for:*					
	0 weeks		2 weeks			
1	24	24	72	73	57	56
2	7	6	6	8	--	--
3	18	18	86	79	--	--
4	7	6	45	45	--	--

* These values are on an air-dry basis for single samples.

In view of the poor reproducibility of the Iowa procedure, it was slightly modified for further testing. Instead of using 10 gm. of soil and leaching with 60 ml. of water, 20 gm. of soil sample were taken and they were leached with 125 ml. of water. During analysis this leachate was clarified with $CuSO_4$, $Ca(OH)_2$, and carbon black according to the procedure given in the Appendix 1 for nitrate determination. The results obtained are given in Table XI under (a).

TABLE XI. Nitrate-Nitrogen Production in Four Soils by the Modified Iowa Methods (Note: Soils were incubated for 2 weeks at 35°C.)

Soil No.	(a) With 20 gm. soil sample*		(b) Low suction applied for 45 sec.*		
1	66	15	22	2	3
2	2	4	Did not determine		
3	27	86	48	15	60
4	13	9	Trace	Trace	6

* These values are on an air-dry basis for single samples.

The replicate samples show large variations. These variations are not due to heterogenity in the soil samples. They might be due to different degrees of compaction caused by the strong suction used while leaching the soils prior to incubation. In order to determine whether soil compaction was causing the variable results in the modified method, further tests were conducted. The excess water was removed by using very little suction (3.46 lb. per square inch). The suction was applied for 45 seconds after free draining had stopped. The soils were incubated at 35°C. in a chamber whose atmosphere was kept saturated. The results obtained are given in Table XI under (b). These data again show large variations between replicate samples. Because of the unsatisfactory results obtained in these tests, no further work was done with the Iowa method.

OBJECTIVES OF THE MAIN INVESTIGATION

The preliminary studies on four soils indicated that a relationship seems to exist between nitrate accumulation and the response of soils to nitrogen fertilization in the field. The main investigation therefore aimed at determining the usefulness in Alberta of several types of tests for determining the need for fertilizer nitrogen. Evaluation of the nitrification test as a means of determining nitrogen requirements was the principal object of this work. There were also several secondary objectives of the investigations. Some of these secondary objectives were to determine:

1. Whether there is a relationship between available nitrogen determined by the Wisconsin method and yield data, nitrate accumulation, etc.
2. The 'N values' of these soils and to see if these are related to yield data, to nitrogen uptake by plants, to nitrate accumulation, etc.
3. Whether nitrogen uptake is correlated with nitrate accumulation or available nitrogen determined by the Wisconsin method, etc.

4. The percentage recovery of nitrogen added to crops in the greenhouse.
5. The response of soils to the addition of different levels of nitrogen in greenhouse.
6. The characteristics of the soils under study.

MATERIALS AND METHODS

A. Materials

Most of the fifty soils used in this study were taken from sites where field fertilizer trials had been or were being conducted by the Department of Soil Science, University of Alberta. A few soil samples were collected from sites where field trials had been conducted by some of the experimental stations of the province. Some of the sites chosen were those which had responded to the application of fertilizer nitrogen and some which had not responded. The sites where soil samples were collected were situated in the six soil zones of Alberta. These soils had been subjected to different cropping and management practices and represented some of the variations which might be encountered in soil samples submitted by farmers seeking fertilizer recommendations. General information about these soils is given in Table XII. A composite soil sample was collected at each location by taking equal amounts of soil to a depth of about six inches from sixteen uniformly spaced places. The quantity of the composite sample was about 80 to 100 pounds. Sampling was done during the two weeks period from June 25, 1956 to July 10, 1956.

Sample Preparation:

The samples were rapidly air dried at the laboratory, crushed, and passed through a one cm. screen. The soil samples thus prepared were used in the greenhouse experiments. For laboratory investigations about six pounds of the soil samples were crushed in a wooden rollered machine to pass

TABLE XII. General Information About the Fifty Soils

Soil No.	Farmer's Name	Address	Legal Location
Black Zone			
S- 1	Leminsky	Vegreville	NE 5-44-12-4
S- 2	Roose	Camrose	SW 3-47-19-4
S- 3	Lother	Nisku	NW 36-50-25-4
S- 4	Galloway	Ft. Saskatchewan	SW 18-54-22-4
S- 5	Tellier	Morinville	SE 22-56-26-4
S- 6	Sinclair	R.R.8, Edmonton	SE 11-54-25-4
S- 7	Peterson	Alix	SW 9-34-22-4
S- 8	Oldford	Red Deer	SW 9-37-27-4
S- 9	Lenz	Bentley	SE 17-40- 1-5
S-10	Morton	Didsbury	SW 23-31- 2-5
S-11	Kneller	Wetaskiwin	SW 1-46-24-4
S-12	-------	Malmo	-------
Thin Black Zone			
S-13	Ralph	Vermilion	SW 30-21- 6-4
S-14	Cliff	Sedgewick	NE 5-44-12-4
S-15	Moser	Killam	NE 23-44-14-4
S-16	Victor	Airdrie	NE 32-27- 1-5
S-17	Summer	Sheppard	SE 34-22-28-4
S-18	Ralph	Stavely	SE 18-14-26-4
S-19	Dower	Woolford	SW 21- 3-24-4
S-20	Fraser	Wainwright	NE 12-47- 7-4
Degraded Black Zone			
S-21	Coley	Clyde	SW 2-60-25-4
S-22	Duchalke	Stony Plain	SW 6-52-27-4
S-23	Kaman	Thorsby	SW 1-48-28-4
S-24	Niddrie	Olds	SE 20-33- 4-5
S-25	Jones	Sunnynook	31-48- 2-5
S-26	Olsen	Rimby	SW 15-42- 2-5
S-27	Tyrell	Duffield	SW 23-52- 3-5
Grey Wooded Zone			
S-28	Gillespi	Bluffton	NW 12-43- 3-5
S-29	Reid	Bluffton	SW 5-45- 2-5
S-30	Johnson	Harmatton	SW 25-32- 4-5
S-31	Kvarnburg	Warburg	NE 32-48- 3-5
S-32	Green	Westrose	SW 4-47- 2-5
Dark Brown Zone			
S-33	Cole	Brownfield	SW 13-39-10-4
S-34	Merchant	Coronation	SE 34-36-11-4
S-35	Hans	Rowley	NE 27-32-21-4

(Continued on next page)

TABLE XII. General Information About the Fifty Soils (Continued)

Soil No.	Farmer's Name	Address	Legal Location
Dark Brown Zone			
S-36	Stevenson	Delia	SW 9-31-18-4
S-37	Bruce	Michichi	NE 30-30-18-4
S-38	Schmaltz	Beiseker	SE 7-28-25-4
S-39	Christenson	Chancellor	SW 26-24-21-4
S-40	McKinnon	Carseland	SW 9-22-25-4
S-41	Galbraith	Vulcan	NE 8-16-25-4
S-42	Yorganson	Claresholm	S 31-11-27-4
S-43	Hogenson	Sterling	NW 33- 7-19-4
Brown Zone			
S-44	Univ. of Alberta	Youngstown	SE 28-28-10-4
S-45	Leth. Substation	Acadia Valley	SE 7-26- 2-4
S-46	Malm	Vauxhall	SE 18-13-16-4
S-47	Dies	Warner	SW 11- 4-17-4
S-48	Grossfield	Duchess	SW 3-19-13-4
S-49	Healy	Veteran	SW 14-35- 9-4
S-50	Sziloggi	Tilley	S1/2 1-18-13-4

a two mm. sieve. The sieved soils were thoroughly mixed. About 400 gm. of each soil were leached with distilled water as described in the preliminary studies, page 34. The leached soils were rapidly air dried to avoid nitrification, and they were then passed through the two mm. sieve again. For each sample about one-half pound of unleached soil which had been passed through the two mm. sieve was ground in a Braun pulverizer type UA to pass twenty mesh sieve. This soil was used in the determination of organic carbon, nitrogen, and available nitrogen by the Wisconsin method.

B. Greenhouse Experiments

For the greenhouse experiments 25 pounds of each soil which had been passed through a one cm. screen were thoroughly mixed with 25 pounds of clean builder's sand. Four pounds of the soil-sand mixture were put in each of 12 pots. The pots were six-inch diameter in size. They had been coated on the inside with asphalt to prevent the movement of any added fertilizer to the outside through pores. A basic application of phosphorus at the rate of 50 pounds P_2O_5 per acre was given to all pots. The phosphate fertilizer was placed about one inch below the soil surface in the pots. To do this, the surface inch of soil was removed from and then returned to each pot. Nitrogen in the form of ammonium nitrate solution at four levels, 0, 30, 60, and 120 pounds of nitrogen per acre was added. Each treatment was replicated thrice. The treatment with no nitrogen has subsequently been called the check treatment. In order to achieve uniform distribution of the fertilizer nitrogen in the pots, the ammonium nitrate solution was added to the soil which had been previously moistened; after the addition of the fertilizer solution, the soils were lightly watered. All fertilizer applications were based on assumed soil weight of 2,000,000 pounds per acre.

The first experiment was started on October 18 and 19, 1956. Victory oats were grown as the crop. Twenty-one seeds were placed in each pot. A week after germination, the number of plants in the pots was thinned to fifteen. The growing plants were supported by three strings which were circled around four bamboo sticks placed in each pot. Temperature in the greenhouse was maintained at about 55°F. from October 18 to December 17, 1956. Temperature was increased to about 65°F. from December 18 to December 26, 1956 in order to promote increased growth of the plants. Watering with tap water was done as and when necessary. The percolation of water through the pots was almost completely avoided. If there was any percolate, it was collected in aluminum plates placed underneath the pots. In a few cases where percolation occurred, the leachate was washed back from the plate into the pot. Artificial light was put on from October 27, 1956; the timing was from 4:00 p.m. to 2:00 a.m. From November 21, 1956 the timing changed and was from 2:00 a.m. to 10:00 p.m. The basic design of the experiment was an ungrouped randomized experiment. However, the pots on each bench were moved two ways every week after germination so as to offset the local effects of light, temperature, and other factors. The first experiment was terminated on December 28, 1956, at which time plants were beginning to form heads. Plants were harvested by cutting at the surface of the soil. They were air dried at a temperature of about 100 to 105°F. for about three weeks and weighed.

The second crop was planted on December 29, 1956. In order to break the soil crust, the surface soil in the pots was stirred before putting in the second crop. Details of the experiment for the second crop were similar to the first one with the following exceptions.

1. No fresh fertilizer treatments were given.

2. Twenty-five seeds were put in and they were thinned to twenty later.

The crop was harvested on March 9 and 10, 1957.

The third crop was planted on May 16 and 17, 1957. Because of the poor physical condition of the soils at the end of the second experiment the pots were emptied, clods were broken, and the soil was air dried. In order to improve the physical condition of the soils, 'perlite' was added. 'Perlite' or 'Earth Aid' is an inert, commercial product used as a soil conditioner in greenhouses. It is a treated silicate rock in origin and contains 71 per cent SiO_2, 13 per cent Al_2O_3, and other constituents such as CaO, MgO, Fe_2O_3, Na_2O, and K_2O. Locally it is available from Calta Distributors. Composite soil samples of about 100 gm. from the replicates of each level of nitrogen were taken for laboratory analysis before adding the 'perlite'. 'Perlite' was added to the soil-sand mixture in the ratio of 1:11 by weight. Four ounces of 'perlite' were mixed with two pounds and twelve ounces of soil-sand mixture. 'Perlite' passing 2.0 mm. but held by 0.246 mm. (60 mesh) sieve was used. Superphosphate at the rate of 200 pounds of P_2O_5 per acre was mixed with the soil-sand-'perlite' mixture before potting the mixture. The soil-sand-'perlite' mixtures were put back in their respective pots. The rates of nitrogen fertilizer used in experiment one were maintained and the previous identity of soils, pots, and treatments were retained. The other details of the experiment were similar to those of the second crop except for the following:

1. Because of increased sunlight intensity and longer days, no artificial light was used.
2. Because of the intense sunlight, temperature could not be controlled and it fluctuated between 55°F. and 90°F.

The plants were harvested on July 15, 1957, about a week after they had started forming heads.

The fourth experiment was started on August 6 and 7, 1957. Before seeding, composite soil samples of about 100 gm. from the replicates of each level of nitrogen were taken from ten soils. Five of these soils were ones which had responded comparatively well to the application of fertilizer nitrogen and the other five were those which had shown comparatively little response to fertilization. These samples were analyzed in the laboratory subsequently. Higher levels of nitrogen fertilizer were employed in the fourth greenhouse experiment. Nitrogen at the rate of 0, 120, 240, and 480 pounds per acre was added. Previously unfertilized pots were maintained as checks and 120, 140, and 480 pounds of nitrogen per acre were added to pots which had been previously treated with 30, 60, and 120 pounds of nitrogen per acre, respectively. Other details of the experiment were similar to those for the third crop. The crop was harvested on October 9 and 10, 1957.

The fifth experiment was commenced on October 16, 1957. It was carried out using only 30 soils. These soils were selected on the basis of the F values obtained from experiment No. 3. Fifteen of these soils gave comparatively high F values and the other fifteen gave comparatively low F values. The details of the experiment were similar to those for the second crop. The crop was removed on December 18 and 19, 1957, about a week after the plants had started forming heads.

The maximum difference between triplicate in any experiment was 1.4 gm. and the average difference within triplicate was 0.32 gm.

C. Laboratory Studies

The soils collected and the plant material obtained in the greenhouse experiments were analyzed in the laboratory. Different tests such as nitrification, the Wisconsin method, 'N' values were carried out on the soils so as to determine the quantity of available nitrogen present. The plant material was analyzed for nitrogen content. Other characteristics

of the soils were also determined. The procedures followed in the laboratory analyses were as follows:

1. The procedures for determining field moisture capacity, incubation of soils mixed with vermiculite for nitrification, and determination of nitrate which accumulated were the same as those already described in the section on preliminary studies. The samples were incubated in 16 ounce wide-mouthed bottles fitted with rubber stoppers having a small hole instead of using 8 ounce jars.
2. Nitrogen in the soil and plant samples were determined by the A.O.A.C. method (10) except that the ammonia distilled off was collected in four per cent boric acid solution and titrated using a mixed indicator composed of methyl red and brom cresol green, instead of collecting ammonia in standard acid. The finely ground soil samples were used for nitrogen determination and the data are expressed on oven dry basis. The composite samples of plant material from the three replicates of each treatment were cut into small pieces and were then ground in a small Wiley mill to pass through a twenty mesh sieve. The ground material was thoroughly mixed. Nitrogen was determined on air dry samples and the results expressed are on air dry basis.
3. The Wisconsin method for determining available nitrogen is given in Appendix 2. According to that method, a one gm. soil sample is used. However, it was felt that a more representative soil sample would be obtained by using ten gm. of soil. When a sample of this size was used, the ammonia distilled could be determined by titration against standard sulphuric acid. Before determination of available nitrogen by the Wisconsin method, a preliminary study was conducted using one soil to determine:

   (a) The effect of boiling the soil and oxidizing mixture for different lengths of time.

(b) The effect of different quantities of oxidizing mixture mixed with the same amount of soil.

(c) Effect of different quantities of soil mixed with equal quantities of oxidizing mixture.

The results obtained are given in Table XIII. These data show that when a small quantity of soil sample was taken and when the proportion of oxidizing mixture was small compared to the weight of the soil, the values obtained were low. The quantity of ammonia distilled over increased with increase in boiling time.

In the light of these results, it was decided to take ten gm. of soil sample and mix it with an equal quantity of the oxidizing mixture. The soil and the oxidizing mixture were placed in an 800 ml. Kjeldahl flask and about 150 ml. of distilled water were added. Paraffin was added to reduce frothing. The contents were brought to boil in five to seven minutes and boiling was continued for five minutes. The distilled ammonia was titrated against .0149 N. sulphuric acid using a mixed indicator composed of methyl red and brom cresol green. In some soils rich in organic matter, in spite of using about two gm. of paraffin wax, there was considerable foaming with the result that the heating switch had to be turned off and on two to three times. Available nitrogen was also determined by the Wisconsin method with the exception that the ammonia in the unknown was determined by nesslerization using the Bausch and Lomb colorimeter, with wave length set at 405 mu. instead of using Nessler tubes.

4. Soil reaction was determined on a saturated paste according to procedure described by Doughty (50). A Beckman pH meter, Model N, was used.

5. Mechanical composition of the soils was determined by the modified pipette method described by Toogood (161).

TABLE XIII. Available Soil Nitrogen Determined by Modification of the Wisconsin Method

Quantity of soil sample	Time of boiling	Quantity of oxidizing mixture	Available nitrogen in pounds per acre*
1 gm.	5 min.	1 gm.	210
3 gm.	5 min.	3 gm.	196
5 gm.	5 min.	5 gm.	299
7 gm.	5 min.	7 gm.	275
10 gm.	5 min.	10 gm.	261
5 gm.	1 min.	5 gm.	Nil
5 gm.	4 min.	5 gm.	244
5 gm.	7 min.	5 gm.	362
5 gm.	10 min.	5 gm.	468
5 gm.	15 min.	5 gm.	498
10 gm.	1 min.	10 gm.	Nil
10 gm.	4 min.	10 gm.	242
10 gm.	7 min.	10 gm.	418
10 gm.	10 min.	10 gm.	570
10 gm.	5 min.	1 gm.	55
10 gm.	5 min.	3 gm.	111
10 gm.	5 min.	5 gm.	158
10 gm.	5 min.	7 gm.	241
10 gm.	5 min.	10 gm.	261

* Average of duplicates on the same soil.

6. Cation exchange capacities and exchangeable cations in the soils were determined according to the procedure described by Pawluk (121) with the following modifications:

   (a) Exchangeable hydrogen was determined without dilution of the ammonium acetate extract with water.

   (b) Exchangeable cations in the residue were extracted according to the procedure given in United States Department of Agriculture Handbook No. 60 (167) using .2 N. HCl instead of .1 N. acetic acid.

   (c) For determining exchangeable sodium and potassium with the flame photometer, no 'buffer solution' was used.

7. Organic carbon in soil is usually determined by the Walkley (178) wet digestion method using diphenylamine as an indicator. This indicator does not give a sharp end point. In order to determine the exact end point, it was decided to carry out an amperometric titration of the solutions. A procedure for the amperometric titration of the excess of $K_2Cr_2O_7$ was worked out under the direction of Dr. W.E. Harris, Department of Chemistry, University of Alberta. The details of this procedure are given in the Appendix 3. The digestion of the soil sample was done by a slight modification of the Walkley method. The soil sample was digested with the oxidizing solution on a steam bath for 30 minutes instead of 15 minutes at room temperature. After the amperometric titrations were completed, the excess of $K_2Cr_2O_7$ was also determined by its titration against standard ferrous ammonium sulphate using sodium diphenylamine sulphonate as an indicator as well. This indicator also gave sharp end point. The results of organic carbon determinations obtained by using the two titration techniques were therefore compared and are given in Table XIV. These data show that the values obtained with the amperometric titration

TABLE XIV. Organic Carbon in Fifty Soils Determined by Two Titration Methods

Soil No.	% by ampero-meteric method*	% by indicator method *
Black Zone		
S- 1	2.78	2.81
S- 2	3.18	3.27
S- 3	2.63	2.41
S- 4	4.21	4.15
S- 5	2.76	2.74
S- 6	4.47	4.31
S- 7	4.05	4.06
S- 8	3.31	3.43
S- 9	4.54	4.50
S-10	3.90	4.19
S-11	4.08	4.12
S-12	4.49	4.49
Thin Black Zone		
S-13	3.96	3.85
S-14	1.55	1.58
S-15	2.80	2.79
S-16	4.62	4.94
S-17	2.88	2.99
S-18	1.43	1.67
S-19	2.48	2.66
S-20	1.92	1.78
Degraded Black Zone		
S-21	2.10	2.05
S-22	1.10	1.16
S-23	1.29	1.29
S-24	1.52	1.72
S-25	1.04	1.14
S-26	2.45	2.44
S-27	2.43	2.46
Grey Wooded Zone		
S-28	2.08	2.14
S-29	1.26	1.33
S-30	3.94	4.77
S-31	2.72	2.88
S-32	2.93	3.12
Dark Brown Zone		
S-33	2.09	2.22
S-34	1.85	1.85
S-35	2.67	2.75
S-36	1.30	1.56
S-37	1.93	2.17
S-38	3.34	3.56
S-39	1.97	2.24
S-40	1.07	1.16
S-41	1.48	1.62
S-42	1.19	1.24
S-43	1.17	1.34
Brown Zone		
S-44	1.24	1.30
S-45	0.78	0.86
S-46	1.32	1.38
S-47	0.85	1.02
S-48	1.38	1.63
S-49	1.89	1.97
S-50	0.87	1.01

* Data are based on oven dry soils and averages of duplicates.

method were generally a little lower than the values obtained using the indicator method. The organic carbon percentages reported in this study are based on the analysis done by using sodium diphenylamine sulphonate as an indicator. It is considered that only 75 per cent of organic carbon present in a soil sample is oxidized by wet digestion procedure. The values reported later on were calculated, therefore, by multiplying the organic carbon percentage determined by the indicator method by 1.333.

8. 'N' value for each soil was determined from a linear regression equation which was calculated after determining the total nitrogen uptake by oats at the four levels of nitrogen in the first greenhouse experiment. The nitrogen uptake under a particular level of nitrogen application was found by multiplying yield by the nitrogen content of the crop. Instead of drawing and extrapolating the regression line to the x-axis to find the 'N' value (109), it was obtained by substituting zero value for y in the regression equation. The negative value of x thus determined was the 'N' value for the soil.

The calculation of 'N' value is illustrated by taking an example. For one soil when 0, 30, 60, and 120 pounds of nitrogen per acre were added to the soil, the nitrogen uptake by plant material of experiment No. 1 was 41.3, 50.7, 58.1, and 73.6 mg., respectively. When these values are plotted on a graph as shown in Figure 5, an almost linear relationship was found. Based on these data, a linear regression equation showing the relation of nitrogen uptake for the given levels of nitrogen was calculated. The equation obtained is $y = 55.9 + .266 (x - 52.5)$. On substituting the value of $y = 0$, a negative value of x equal to 158 is obtained. This value is the determined 'N' value and is a measure of the available nitrogen content of the soil in pounds per acre and is in terms of ammonium nitrate nitrogen.

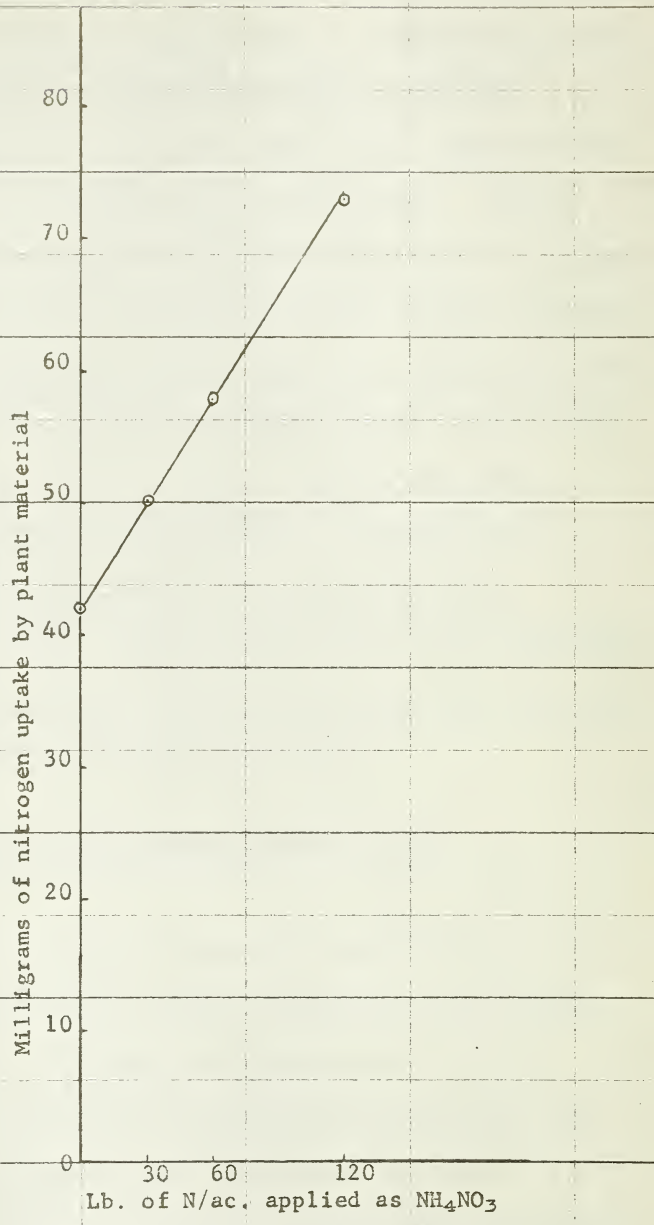

FIGURE 5. Relationship of nitrogen uptake by plant material in experiment No. 1 to different levels of fertilizer nitrogen applied on one soil.

RESULTS AND DISCUSSION

A. Characterization of Soils

Some characteristics of the fifty soils collected for this study were determined. The analyses made were soil reaction, mechanical composition, estimated field capacity, total nitrogen, organic carbon, exchangeable cations, and cation exchange capacity. The data obtained are given in Table XV. While pH of the soils varies from 5.4 to 7.7, they appear to be representative of common Alberta soils. Normal variations in soil texture occur. Within the various zones, nitrogen content seems to be higher in the heavier textured soils. The carbon-nitrogen ratio seems to be related to the climate, increasing progressively from the warm semi-arid areas of the brown zone to the cooler more humid areas of the other zones. Cation exchange capacities of the soils vary between 11.0 and 46.4 m.e. per 100 gm. of soil. Calcium is without exception the dominant cation on the exchange complex. In general, the characteristics of these soils are similar to those reported by other investigators (15, 21, 118, 122, 188). The variations found in the properties of these soils were to be expected because the soil samples had been collected from widely separated sites in all six Alberta soil zones.

B. Relationship of Nitrogen Tests to Greenhouse and Field Yields

a. Nitrate accumulation

Nitrate accumulation in soils as previously stated has been used successfully by certain investigators as a method of predicting the nitrogen fertilizer requirements of soils. Following preliminary studies of the method, described earlier, the technique was tested on the fifty soils used in this study. Three different treatments and incubations were used. The data obtained are given in Table XVI. In order to determine the relationship between nitrate accumulation and crop yield data, the yields were obtained from greenhouse and field experiments and are given in Tables XVII (A-E) and XVIII.

TABLE XV. Analytical Data for the Fifty Soils

Soil No.	pH	Texture: Sand %	Clay %	Silt %	Class	Est. field cap.%	Total N %	Organ. C %	C/N Ratio	Exchangeable cations m.e./100 gm.: Ca	Mg	Na	K	H	C. E. C. m.e./100 gm.: By sum	By test
Black Zone																
S- 1	5.8	48	18	34	L	56	0.30	3.7	12.5	15.3	4.3	0.1	0.4	3.7	23.8	22.7
S- 2	6.0	41	19	40	L	58	0.36	4.4	12.0	16.9	4.6	0.9	0.8	4.5	27.7	25.7
S- 3	6.7	54	17	29	SL	52	0.25	3.2	13.0	26.1	3.9	0.1	0.2	1.2	31.5	19.0
S- 4	6.3	7	52	41	SiC	69	0.48	5.5	11.5	35.4	9.2	0.1	0.9	3.6	49.2	45.3
S- 5	5.5	27	25	48	L	56	0.33	3.7	11.0	10.3	3.4	2.0	0.3	5.9	21.9	24.5
S- 6	5.8	9	34	57	SiCL	67	0.51	5.7	11.5	30.7	6.4	0.1	0.7	3.9	41.8	38.7
S- 7	5.9	36	21	43	L	66	0.43	5.4	12.5	20.4	5.6	0.0	1.2	4.4	31.6	29.5
S- 8	6.6	37	22	41	L	65	0.35	4.6	13.5	27.8	5.4	0.1	1.0	2.5	36.8	31.5
S- 9	5.9	8	42	50	SiC	73	0.54	6.0	11.0	35.6	8.2	0.2	0.6	4.3	48.7	46.4
S-10	6.6	26	25	49	L	62	0.43	5.6	13.0	27.5	4.2	0.1	0.8	2.7	35.3	32.1
S-11	6.2	40	29	31	CL	65	0.49	5.5	11.5	27.6	8.5	0.4	0.6	3.4	40.5	37.5
S-12	6.4	17	37	46	SiCL	74	0.47	6.0	13.0	31.9	7.7	0.1	0.7	2.7	43.1	39.9
Thin Black Zone																
S-13	5.6	42	23	35	L	69	0.33	5.1	15.5	20.1	5.8	0.1	1.0	4.5	31.5	30.3
S-14	6.5	80	7	13	LS	38	0.15	2.1	14.0	9.2	3.5	0.1	0.5	1.8	15.1	12.4
S-15	5.8	34	25	41	L	56	0.24	3.7	15.5	15.7	4.7	0.1	1.0	3.8	25.3	23.7
S-16	6.7	26	28	46	CL	76	0.52	6.6	12.5	32.1	3.6	0.1	0.9	1.2	37.9	28.6
S-17	6.8	35	24	41	L	65	0.32	4.0	12.5	25.4	5.2	0.3	1.0	1.2	33.1	26.4
S-18	6.9	43	22	35	L	50	0.19	2.2	12.0	18.4	3.0	0.1	1.1	0.8	23.4	18.2
S-19	6.1	22	41	37	C	57	0.29	3.6	12.5	23.5	4.8	0.1	1.8	3.1	33.3	30.3
S-20	6.0	30	24	46	L	55	0.22	2.4	11.0	13.7	4.3	0.0	0.6	3.2	21.8	20.8
Degraded Black Zone																
S-21	6.2	53	16	31	SL	49	0.25	2.7	11.0	12.0	3.4	0.9	0.7	2.7	19.7	18.7
S-22	6.6	74	7	19	LS	39	0.12	1.5	12.5	9.5	1.0	0.0	0.5	1.6	12.6	11.0
S-23	6.0	30	16	54	SiL	48	0.14	1.7	12.5	10.7	2.0	0.1	0.3	2.6	15.7	14.7
S-24	6.1	21	18	61	SiL	49	0.18	2.3	13.0	13.8	2.2	0.1	0.4	3.2	19.7	17.4
S-25	6.8	47	19	34	L	50	0.14	1.5	11.0	13.6	4.5	0.5	1.1	1.3	21.0	16.0
S-26	6.0	28	23	49	L	54	0.27	3.3	12.0	22.2	3.2	0.1	0.7	3.4	29.6	28.8
S-27	6.4	42	18	40	L	53	0.27	3.3	12.0	22.1	2.6	0.0	0.5	2.5	27.7	24.9

(Continued on next page)

TABLE XV. Analytical Data for the Fifty Soils (Continued)

Soil No.	pH	Texture: Sand %	Clay %	Silt %	Class	Est. field cap. %	Total N %	Organ. C %	C/N Ratio	Exchangeable cations m.e./100 gm.: Ca	Mg	Na	K	H	C. E. C. m.e./100 gm.: By sum	By test
Grey Wooded Zone																
S-28	5.9	28	21	51	SiL	52	0.26	2.9	11.0	15.5	1.9	0.0	0.5	3.5	21.4	21.7
S-29	5.7	43	13	44	L	43	0.13	1.8	13.0	8.0	1.6	0.0	0.4	3.4	13.4	13.1
S-30	6.0	23	25	52	SiL	70	0.47	6.4	13.5	26.7	3.6	0.1	0.6	5.1	36.1	34.7
S-31	6.0	17	33	50	SiCL	61	0.25	3.8	15.5	22.4	5.6	0.2	0.6	3.9	32.7	30.9
S-32	6.8	33	23	44	L	59	0.30	4.2	14.0	32.2	4.1	0.1	0.5	2.2	39.1	34.3
Dark Brown Zone																
S-33	5.7	50	20	30	L	50	0.25	3.0	12.0	12.6	3.5	0.0	0.7	3.7	20.5	19.5
S-34	5.7	46	23	31	L	51	0.21	2.5	11.5	9.4	5.2	1.2	0.8	3.7	20.3	19.3
S-35	5.4	26	48	26	C	65	0.31	3.7	12.0	19.2	7.8	0.3	1.2	5.1	33.6	33.3
S-36	7.4	14	58	28	C	73	0.19	2.1	10.5	39.8	11.0	0.6	1.3	0.0	52.7	40.0
S-37	5.4	35	35	30	CL	56	0.23	2.9	12.5	10.2	6.3	0.4	1.2	4.5	22.6	22.4
S-38	6.7	36	20	44	L	59	0.36	4.7	13.0	25.1	4.2	0.1	1.0	1.6	32.0	26.1
S-39	5.7	20	35	45	CL	55	0.25	3.0	12.0	15.2	6.0	0.1	1.3	4.3	26.9	26.0
S-40	7.3	71	12	17	SL	39	0.12	1.6	12.5	13.1	1.8	0.0	0.5	0.0	15.4	12.8
S-41	6.3	40	21	39	L	51	0.18	2.2	12.5	15.4	3.3	0.0	0.7	2.5	21.9	20.0
S-42	7.7	53	20	27	SL	50	0.15	1.7	10.5	30.7	3.3	0.2	1.0	0.0	35.2	16.0
S-43	7.1	47	29	24	SCL	53	0.17	1.8	10.5	16.0	4.8	0.2	0.7	1.5	23.2	35.3
Brown Zone																
S-44	6.8	53	15	32	SL	48	0.16	1.7	11.0	8.9	3.5	1.7	0.5	1.4	16.0	12.5
S-45	7.3	60	16	24	SL	44	0.11	1.2	11.0	10.1	2.8	0.0	0.8	0.9	14.6	11.5
S-46	7.3	35	22	43	L	54	0.17	1.8	11.0	20.2	6.9	0.9	1.0	0.0	29.0	19.3
S-47	7.4	37	20	43	L	45	0.13	1.4	10.5	28.7	7.4	0.1	1.0	0.0	37.2	16.6
S-48	7.3	15	25	60	SiL	51	0.20	2.2	11.0	19.5	7.9	0.4	0.9	0.8	29.5	23.4
S-49	5.5	48	22	30	L	51	0.23	2.6	11.5	8.5	3.9	0.2	1.4	3.9	17.9	18.2
S-50	7.5	39	22	39	L	49	0.13	1.4	10.5	20.8	5.6	0.2	0.9	0.0	27.5	18.4

NOTE: Total N and organic C determinations were done in duplicate; all other data are results of a single determination.

TABLE XVI. Nitrate-Nitrogen Accumulation on Incubation in the Fifty Soils

Soil No.	NO_3-N p.p.m. initially present (1)	NO_3 - N p.p.m. accumulation (1) Unleached soil (2) 2 weeks at 28°C.	Unleached soil (2) 4 weeks at 15°C.	Leached soil (3) 4 weeks at 15°C.
Black Zone				
S- 1	14	70	39	58
S- 2	16	81	41	64
S- 3	3	31	16	6
S- 4	17	70	44	61
S- 5	28	96	67	60
S- 6	102	136	103	77
S- 7	22	96	66	76
S- 8	10	73	49	58
S- 9	36	80	54	75
S-10	10	104	69	84
S-11	9	86	57	85
S-12	6	88	55	80
Thin Black Zone				
S-13	53	132	80	85
S-14	30	55	36	28
S-15	14	74	54	58
S-16	14	112	80	104
S-17	5	70	45	70
S-18	5	68	42	47
S-19	18	86	56	71
S-20	6	51	30	30
Degraded Black Zone				
S-21	22	79	60	58
S-22	1	37	11	26
S-23	6	64	30	22
S-24	7	74	54	11
S-25	4	64	43	54
S-26	14	67	40	29
S-27	28	72	42	52

(Continued on next page)

TABLE XVI. Nitrate-Nitrogen Accumulation on Incubation in the Fifty Soils

(Continued)

Soil No.	NO_3-N p.p.m. initially present (1)	NO_3 - N p.p.m. accumulation (1) Unleached soil (2) 2 weeks at 28°C.	Unleached soil (2) 4 weeks at 15°C.	Leached soil (3) 4 weeks at 15°C.
Grey Wooded Zone				
S-28	3	60	27	19
S-29	10	57	18	18
S-30	7	94	70	55
S-31	8	74	26	40
S-32	4	76	50	72
Dark Brown Zone				
S-33	12	60	36	34
S-34	25	65	46	49
S-35	8	81	48	63
S-36	16	52	31	56
S-37	7	57	38	51
S-38	16	84	54	79
S-39	4	70	39	53
S-40	6	38	20	31
S-41	3	56	37	52
S-42	11	52	39	48
S-43	28	60	36	50
Brown Zone				
S-44	86	120	97	100
S-45	2	46	22	34
S-46	13	60	42	53
S-47	10	44	29	27
S-48	20	67	45	57
S-49	14	59	37	52
S-50	7	64	42	58

(1) Average of duplicates on air dry basis.
(2) These figures represent increase in NO_3-N over and above amounts initially present.
(3) These figures represent the increase from an initial content of zero.

TABLE XVII (A). Oat Crop Yields in Greenhouse Experiment No. 1

(Note: Each figure is the average weight of air dry plant material from three pots weighed to the nearest 0.1 gm.)

Soil No.	Check Yield	Yield increases with N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Black Zone						
S- 1	2.03	.10	.20	.13	1.25	--
S- 2	2.20	.33	.26	.63	8.12**	.29
S- 3	1.26	.30	.30	.40	6.55*	.24
S- 4	2.10	.20	.63	.83	7.54*	.45
S- 5	1.60	.10	.16	.20	<1	--
S- 6	2.60	-.07	-.10	-.14	<1	--
S- 7	2.76	-.10	.00	.17	<1	--
S- 8	2.33	.40	.77	.93	17.20**	.32
S- 9	2.23	.33	.53	.73	12.36**	.29
S-10	2.43	.37	.33	.70	2.53	--
S-11	2.30	.16	.40	.46	3.03	--
S-12	1.76	.50	.64	.87	10.41**	.37
Thin Black Zone						
S-13	2.83	.10	.13	.18	2.92	--
S-14	2.20	.03	.33	.53	9.65**	.26
S-15	2.20	.23	.10	.43	9.46**	.20
S-16	2.30	.16	.23	.50	3.17	--
S-17	2.10	.26	.46	.70	6.87*	.37
S-18	2.10	.40	.56	.80	6.18*	.44
S-19	3.00	.23	.43	.94	5.24*	.54
S-20	1.73	.27	.03	.53	9.15**	.26
Degraded Black Zone						
S-21	2.16	.04	.04	.30	3.70	--
S-22	1.33	.50	.80	.97	108.00**	.13
S-23	1.53	.27	.33	.47	10.36**	.20
S-24	2.73	.17	.33	.67	15.00**	.24
S-25	2.20	.60	.93	1.00	18.54**	.34
S-26	1.86	.04	.27	.47	6.35*	.28
S-27	1.93	.20	.30	.67	9.32**	.29

(Continued on next page)

TABLE XVII (A). Oat Crop Yields in Greenhouse Experiment No. 1 (Continued)

Soil No.	Check Yield	Yield increases with N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Grey Wooded Zone						
S-28	1.90	.16	.26	.43	6.66*	.23
S-29	1.83	.13	.20	.23	3.43	--
S-30	2.43	.13	.27	.47	4.18*	.32
S-31	2.06	.07	.10	.47	4.19*	.33
S-32	2.36	.10	.14	.47	12.30**	.19
Dark Brown Zone						
S-33	1.86	.40	.34	.74	12.00**	.28
S-34	2.40	.10	.36	.50	6.75*	.29
S-35	2.40	.66	.56	1.13	18.57**	.35
S-36	2.10	.30	.46	.66	2.87	--
S-37	2.10	.26	.53	.90	21.09**	.27
S-38	2.56	.07	.20	.50	4.36*	.34
S-39	2.56	.54	.87	1.20	13.74**	.45
S-40	2.10	.56	1.06	1.20	20.43**	.39
S-41	2.10	.63	.80	1.00	19.48**	.32
S-42	1.73	.50	.70	.80	23.75**	.24
S-43	3.06	.54	.54	1.00	10.00**	.42
Brown Zone						
S-44	3.30	.26	.30	.53	4.00	--
S-45	1.73	.87	1.43	1.77	38.93**	.12
S-46	2.66	.30	.54	.40	4.08*	.36
S-47	2.03	.30	.83	1.07	35.50**	.26
S-48	3.03	.37	.37	.33	1.07	--
S-49	2.20	.23	.30	.93	23.85**	.26
S-50	2.33	.50	.70	.90	10.20**	.39

* F value significant at the 5 per cent level.

** F value significant at the 1 per cent level.

TABLE XVII (B) Oat Crop Yields in Greenhouse Experiment No. 2

(Note: Each figure is the average weight of air dry plant material from three pots weighed to the nearest 0.1 gm.)

Soil No.	Check Yield	Yield increases with N applied at:(1) 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Black Zone						
S- 1	1.97	.16	.69	1.93	24.16**	.57
S- 2	2.30	.03	.60	1.50	40.61**	.36
S- 3	1.36	-.03	.47	1.14	35.60**	.30
S- 4	1.83	.23	.57	1.37	23.68**	.40
S- 5	3.56	.04	.07	.14	<1	--
S- 6	3.46	-.10	.00	-.43	1.43	--
S- 7	2.46	.37	.34	2.20	36.15**	.54
S- 8	1.73	.17	.47	1.23	119.06**	.16
S- 9	2.20	.06	.43	.66	4.70*	.47
S-10	2.00	.23	.80	1.56	57.20**	.30
S-11	1.86	.34	.54	1.57	100.00**	.22
S-12	1.86	.04	.27	1.17	59.73**	.23
Thin Black Zone						
S-13	4.83	-.20	.17	.50	3.28	--
S-14	1.66	.30	.40	1.47	65.77**	.26
S-15	2.03	.27	.67	1.43	155.46**	.16
S-16	2.53	.07	.47	1.07	9.43**	.52
S-17	1.93	-.03	.30	1.10	25.63**	.34
S-18	1.70	.33	.30	1.23	13.60**	.47
S-19	2.06	.34	.57	1.44	16.29**	.49
S-20	1.60	.33	.06	1.70	253.33**	.16
Degraded Black Zone						
S-21	2.06	.17	.44	1.30	33.43**	.32
S-22	1.40	.06	.20	1.00	40.19**	.24
S-23	1.90	.33	1.00	1.83	209.70**	.58
S-24	1.76	.50	.90	1.67	34.00**	.39
S-25	1.86	.20	.34	.94	15.57**	.33
S-26	1.93	.17	.60	1.83	39.24**	.43
S-27	1.96	.00	.64	1.14	18.68**	.41

(Continued on next page)

TABLE XVII (B) Oat Crop Yields in Greenhouse Experiment No. 2 (Continued)

Soil No.	Check Yield	Yield increases with N applied at: (1) 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Grey Wooded Zone						
S-28	1.83	.13	.47	1.77	22.32**	.55
S-29	1.93	.40	.70	2.20	22.82**	.65
S-30	1.90	.60	.56	1.36	15.70**	.46
S-31	2.33	.10	.50	2.00	13.24**	.83
S-32	1.93	.20	.57	1.47	17.38**	.51
Dark Brown Zone						
S-33	2.00	.26	.63	1.70	33.40**	.42
S-34	2.66	.40	.90	1.94	209.00**	.19
S-35	2.30	.40	.66	1.20	20.00**	.37
S-36	1.66	.24	.30	1.30	44.13**	.28
S-37	2.06	.20	.60	1.80	312.00**	.15
S-38	1.76	.27	.50	1.17	24.06**	.33
S-39	1.86	.40	.40	1.07	6.10*	.58
S-40	1.23	.07	.30	.53	8.80**	.26
S-41	1.60	.06	.33	1.03	53.60**	.21
S-42	1.57	.06	.39	1.43	176.00**	.16
S-43	1.40	.13	.40	1.13	22.84**	.34
Brown Zone						
S-44	3.60	-.60	.06	.66	2.18	--
S-45	1.33	.03	.10	.50	18.28**	.17
S-46	1.46	.07	.50	1.44	11.02**	.63
S-47	1.43	.10	.37	.80	9.57**	.37
S-48	1.63	-.07	.33	1.27	18.08**	.47
S-49	2.30	.30	.80	1.46	58.71**	.23
S-50	1.90	.16	.40	1.13	50.00**	.23

* F value significant at the 5 per cent level.
** F value significant at the 1 per cent level.

(1) No N was added for this experiment. The treatments refer to applications made in Experiment No. 1.

TABLE XVII (C) Oat Crop Yields in Greenhouse Experiment No. 3

(Note: Each figure is the average weight of air dry plant material from three pots weighed to the nearest 0.1 gm.)

Soil No.	Check Yield	Yield increases with N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Black Zone						
S- 1	2.57	.56	1.40	1.23	19.08**	.48
S- 2	3.00	.87	.80	1.07	10.83**	.46
S- 3	2.23	.74	1.24	1.40	86.03**	.22
S- 4	2.60	.47	1.00	.97	11.96**	.44
S- 5	3.63	.74	.94	1.40	10.33**	.59
S- 6	3.73	.47	1.00	1.04	17.02**	.39
S- 7	3.50	.30	.93	1.03	9.70**	.52
S- 8	2.83	.77	1.14	1.40	24.66**	.39
S- 9	2.87	.26	.73	1.03	22.37**	.32
S-10	3.03	.70	.94	1.20	57.88**	.22
S-11	2.63	.67	.90	1.10	16.15**	.39
S-12	3.37	.66	.86	1.00	5.68*	.68
Thin Black Zone						
S-13	2.97	.83	.90	1.46	16.24**	.49
S-14	2.30	.90	1.57	2.13	65.20**	.37
S-15	3.10	.63	.93	1.23	25.63**	.34
S-16	3.23	.50	.67	1.00	14.85**	.35
S-17	2.83	.54	.64	1.04	15.32**	.22
S-18	2.67	.66	1.10	1.43	23.00**	.41
S-19	3.00	.47	.87	1.13	14.66**	.41
S-20	2.50	.77	1.33	1.47	19.79**	.49
Degraded Black Zone						
S-21	2.93	1.10	1.84	2.20	55.09**	.42
S-22	2.30	1.03	2.00	2.87	44.17**	.68
S-23	2.43	.90	1.00	1.20	27.07**	.33
S-24	2.63	.24	.70	.70	6.51*	.44
S-25	2.30	1.17	1.43	1.90	92.37**	.27
S-26	2.73	.44	.64	1.00	10.15**	.42
S-27	3.07	.66	.83	1.33	25.10**	.36

(Continued on next page)

TABLE XVII (C) Oat Crop Yields in Greenhouse Experiment No. 3 (Continued)

Soil No.	Check Yield	Yield increases with N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	F value	L.S.D.
Grey Wooded Zone						
S-28	2.70	.50	.93	1.20	39.06**	.27
S-29	2.37	.70	1.10	1.26	50.84**	.26
S-30	2.73	.47	.87	1.00	10.38**	.45
S-31	2.60	.53	.90	1.07	48.70**	.22
S-32	2.47	.83	.96	1.36	15.84**	.46
Dark Brown Zone						
S-33	2.67	.60	.80	1.26	60.36**	.22
S-34	3.13	.67	1.07	1.50	34.86**	.35
S-35	3.30	.13	.47	.77	6.19*	.45
S-36	2.60	.73	1.43	1.57	44.66**	.35
S-37	3.17	.70	.83	1.03	16.82**	.36
S-38	3.17	.40	.56	.96	7.84**	.46
S-39	3.30	.37	.70	.93	10.95**	.39
S-40	2.03	.84	1.34	2.10	32.70**	.50
S-41	2.30	.83	1.00	1.60	13.97**	.58
S-42	2.37	.83	1.26	2.06	127.42**	.25
S-43	3.07	.33	.83	1.36	27.61**	.37
Brown Zone						
S-44	2.80	.63	1.03	1.70	18.83**	.53
S-45	2.83	.47	1.10	1.34	18.38**	.46
S-46	2.90	.63	1.00	1.47	18.03**	.47
S-47	2.33	.57	1.20	1.44	25.12**	.41
S-48	2.93	.50	.80	1.47	14.12**	.53
S-49	2.80	.73	1.30	1.23	16.34**	.48
S-50	2.63	.57	.80	1.54	25.47**	.41

* F value significant at the 5 per cent level.
** F value significant at the 1 per cent level.

TABLE XVII (D) Oat Crop Yields in Greenhouse Experiment No. 4

(Note: Each figure is the average weight of air dry plant material from three pots weighed to the nearest 0.1 gm.

Soil No.	Check Yield	Yield increase with N applied at: 120 lb./A.	240 lb./A.	480 lb./A.
Black Zone				
S- 1	1.53	2.04	2.60	3.00
S- 2	1.63	1.94	2.84	3.44
S- 3	1.40	2.03	2.37	2.90
S- 4	1.77	2.16	2.73	3.20
S- 5	2.03	1.90	2.64	3.24
S- 6	1.73	2.50	3.10	3.90
S- 7	2.00	2.23	3.07	3.23
S- 8	1.57	2.03	2.90	3.43
S- 9	1.70	1.73	2.67	3.10
S-10	1.60	1.93	2.73	2.80
S-11	1.77	2.30	2.70	3.26
S-12	1.90	1.93	2.60	3.30
Thin Black Zone				
S-13	1.90	2.20	2.63	2.97
S-14	1.47	2.40	2.80	3.23
S-15	1.77	2.30	3.06	3.33
S-16	2.00	1.93	2.17	2.53
S-17	1.50	2.23	2.80	3.60
S-18	1.53	2.24	2.50	3.10
S-19	1.63	2.10	2.74	3.44
S-20	1.57	1.96	2.80	3.06
Degraded Black Zone				
S-21	1.60	2.70	2.93	3.43
S-22	1.40	2.57	3.23	3.60
S-23	1.53	1.74	2.04	2.54
S-24	1.57	1.73	2.43	2.63
S-25	1.43	2.74	3.04	3.70
S-26	1.60	1.90	2.10	2.93
S-27	1.50	2.03	2.97	3.37

(Continued on next page)

TABLE XVII (D) Oat Crop Yields in Greenhouse Experiment No. 4 (Continued)

Soil No.	Check Yield	Yield increase with N applied at: 120 lb./A.	240 lb./A.	480 lb./A.
Grey Wooded Zone				
S-28	1.53	1.87	2.44	2.64
S-29	1.40	1.73	2.53	3.17
S-30	1.70	1.90	2.27	2.33
S-31	1.63	1.67	2.10	2.77
S-32	1.47	2.20	2.53	2.93
Dark Brown Zone				
S-33	1.63	1.94	2.54	3.10
S-34	2.03	2.24	2.64	3.44
S-35	2.07	2.00	2.26	3.23
S-36	1.63	2.94	3.80	4.24
S-37	1.47	2.66	2.83	3.63
S-38	1.97	1.66	2.43	2.13
S-39	1.60	2.37	3.10	3.20
S-40	1.47	2.36	2.90	3.73
S-41	1.37	2.50	2.76	3.33
S-42	1.50	1.93	2.73	3.37
S-43	1.53	2.90	3.40	4.00
Brown Zone				
S-44	1.80	2.30	2.87	3.40
S-45	1.37	2.73	2.86	3.40
S-46	1.47	2.46	3.23	3.50
S-47	1.37	2.10	2.46	2.90
S-48	1.50	2.27	2.87	3.33
S-49	1.63	2.07	3.00	3.74
S-50	1.53	2.40	2.94	3.47

TABLE XVII (E) Oat Crop Yields in Greenhouse Experiment No. 5

(Note: Each figure is the average weight of air dry plant material from three pots weighed to the nearest 0.1 gm.)

Soil No.	Check Yield	Yield increase with N applied at: (1) 120 lb./A.	240 lb./A.	480 lb./A.	F value	L.S.D.
S- 2	1.03	.07	.24	.57	11.88**	.24
S- 3	0.83	.10	.27	.44	44.00**	.09
S- 4	1.03	.00	.37	.74	74.00**	.13
S- 5	1.10	.03	.23	.60	36.80**	.15
S- 7	1.00	.20	.43	.57	16.88**	.20
S-10	0.90	.10	.30	.60	28.00**	.16
S-12	1.00	.07	.33	.67	13.85**	.26
S-14	0.97	.03	.33	.46	17.94**	.17
S-16	1.03	.17	.40	.57	11.88**	.24
S-17	1.00	.07	.13	.57	26.21**	.16
S-21	0.93	.20	.30	.67	11.65**	.26
S-22	0.93	.04	.20	.57	40.60**	.13
S-25	0.93	.20	.54	.77	28.00**	.21
S-26	0.90	.10	.20	.47	13.71**	.17
S-28	0.87	.16	.36	.53	32.66**	.13
S-29	0.80	.17	.30	.43	11.77**	.17
S-30	0.93	.10	.34	.62	19.36**	.20
S-31	1.00	-.03	.30	.47	11.04**	.24
S-32	1.00	.05	.37	.60	66.66**	.12
S-33	1.07	.00	.30	.53	20.00**	.19
S-34	1.13	.14	.47	.60	23.70**	.19
S-35	1.13	.17	.04	.47	8.54**	.24
S-36	1.00	.23	.70	1.20	137.00**	.15
S-38	0.97	.13	.40	.63	7.69**	.33
S-39	0.93	.10	.37	.74	32.30**	.19
S-40	0.90	.07	.20	.77	41.83**	.17
S-41	0.90	.10	.37	.80	20.43**	.25
S-42	0.83	.17	.34	.80	28.56**	.21
S-43	0.83	.20	.54	1.04	44.36**	.22
S-48	0.97	-.10	.23	.53	11.16**	.28

** F value significant at 1 per cent level.

(1) No N applied. Treatments refer to applications made in Experiment No. 4.

TABLE XVIII. Yield Data for Field Experiments with Oats, Barley, and Wheat (1)

Soil No.	Year	Crop	No. of crop after fallow	Straw cover	No P_2O_5 Check yield Cwt./A.	No P_2O_5 Increase with N applied at: 33 lb./A.(2)	No P_2O_5 Increase with N applied at: 67 lb./A.(3)	20 lb. P_2O_5 / A. Check yield Cwt./A.	20 lb. P_2O_5 / A. Increase with N applied at: 33 lb./A.(2)	20 lb. P_2O_5 / A. Increase with N applied at: 67 lb./A.(3)
Black Zone										
S- 1	1956	Oats	2nd	Heavy	Not sampled					
S- 2	1956	Oats	2nd	Heavy	13.2	4.3	5.9	--	--	--
S- 3	1955	Oats	2nd	Medium	7.1	7.2	8.9	9.2	6.9	11.1
S- 4	1955	Barley	2nd	Heavy	14.5	2.1	-0.1	17.8	0.2	0.4
S- 5	1952	Oats	2nd	?	12.0	6.9	--	--	--	--
S- 6	1952	Barley	3rd	?	18.7	1.2	--	--	--	--
S- 7	1955	Barley	3rd	Heavy	13.0	3.7	7.8	19.7	4.3	7.1
S- 8	1955	Barley	3rd	Heavy	11.5	7.3	13.3	11.1	8.4	13.9
S- 9	1952	Barley	3rd	?	16.4	4.8	--	--	--	--
S-10	1955	Barley	2nd	Medium	23.3	5.3	4.8	28.7	-0.8	-7.3
S-11	1956	Barley	2nd	Light	13.6	10.3	10.4	--	--	--
S-12	1956	Oats	?	?	7.0	6.7	--	--	--	--
Thin Black Zone										
S-13	1956	Oats, barley	2nd	?	13.8	1.2	-3.4	--	--	--
S-14	1956	Barley	1st	Nil	18.2	-1.9	7.7	--	--	--
S-15	1956	Oats	2nd	Heavy	25.3	-0.1	10.2	--	--	--
S-16	1955	Oats	2nd	Medium	16.5	3.7	0.8	19.7	3.3	2.1
S-17	1955	Oats	2nd	Heavy	29.4	2.3	1.5	38.8	-0.4	1.3
S-18	1955	Wheat	3rd	Medium	15.2	5.1	8.8	18.1	2.8	7.6
S-19	1956	Oats	1st	Nil	Lodged due to fertilization					
S-20	1956	Wheat	2nd	?	--	--	--	--	--	--
Degraded Black Zone										
S-21	1955	Barley	2nd	Medium	7.6	3.8	5.0	10.9	2.7	3.6
S-22	1956	Oats	2nd	?	7.8	5.7	--	--	--	--
S-23	1954	Barley	2nd	?	4.7	-0.3	-2.1	--	--	--
S-24	1956	Barley	1st	Nil	20.5	2.6	-3.7	23.2	-1.6	-5.1
S-25	1956	Wheat	2nd	?	Only soil sample taken					
S-26	1956	Barley	2nd	?	9.7	2.5	-1.9	--	--	--
S-27	1955	Wheat	1st	Nil	8.2	2.8	--	9.5	1.5	--

(Continued on next page)

TABLE XVIII. Yield Data for Field Experiments with Oats, Barley, and Wheat (1)

Soil No.	Year	Crop	No. of crop after fallow	Straw cover	No P_2O_5 Check yield Cwt./A.	No P_2O_5 Increase with N applied at: 33 lb./A.(2)	No P_2O_5 Increase with N applied at: 67 lb./A.(3)	20 lb. P_2O_5 / A. Check yield Cwt./A.	20 lb. P_2O_5 / A. Increase with N applied at: 33 lb./A.(2)	20 lb. P_2O_5 / A. Increase with N applied at: 67 lb./A.(3)
Grey Wooded Zone										
S-28	1955	Barley	2nd	Heavy	11.6	2.6	6.6	14.6	2.2	4.6
S-29	1955	Barley	2nd	Medium	11.5	0.8	0.6	12.3	0.7	1.7
S-30	1956	Oats	2nd	?	8.4	0.8	4.4	9.1	5.3	7.4
S-31	1956	Barley	2nd	?	7.8	3.0	0.5	--	--	--
S-32	1956	Wheat	2nd	?	7.4	0.5	0.0	--	--	--
Dark Brown Zone										
S-33	1956	Oats	2nd	Medium	14.1	4.8	10.2	--	--	--
S-34	1956	Wheat	2nd	Medium	16.1	1.9	3.7	--	--	--
S-35	1952	Wheat	2nd	?	19.4	-1.6	--	--	--	--
S-36	1956	Wheat	1st	Nil	15.1	1.8	0.7	18.3	3.7	5.5
S-37	1952	Wheat	2nd	?	15.3	4.0	--	--	--	--
S-38	1952	Wheat	2nd	?	11.4	4.5	--	--	--	--
S-39	1955	Barley	2nd	Heavy	22.8	0.2	2.1	23.5	1.2	1.0
S-40	1956	Barley	1st	Nil	6.1	3.7	3.5	7.6	1.8	3.3
S-41	1955	Wheat	2nd	Medium	15.2	2.6	8.1	17.6	5.9	9.2
S-42	1955	Wheat	1st	Nil	14.0	5.6	5.9	18.8	7.8	8.3
S-43	1956	Oats	1st	Nil	Only soil sample taken					
Brown Zone										
S-44	1956	Barley	2nd	?	17.8	2.4	2.7	14.2	1.9	4.0
S-45	1954	Wheat	1st	Nil	21.1	-0.5	--	--	--	--
S-46	1953	Barley	?	?	27.1	4.3	--	--	--	--
S-47	1953	Wheat	1st	Nil	24.5	4.1	--	--	--	--
S-48	1955	Barley	2nd	Light	36.0	5.7	6.0	43.2	3.0	1.3
S-49	1956	Oats	1st	Nil	26.3	4.7	5.0	--	--	--
S-50	1956	Wheat, oats	1st	Nil	Hailed out					

(1) Soil Science Department data with bushels per acre converted to hundredweights per acre.
(2) In some cases application was less than 33 lb.
(3) In this column all applications of over 33 lb. are included. Most of them approached 67 lb.

Details of the field trials are given in the Fertilizer Experiment Reports for 1955 and 1956 prepared by the Department of Soil Science, University of Alberta (148).

Correlation coefficients between nitrate accumulation and greenhouse yields are given in Table XIX. There was a significant positive correlation (at P = 0.01) between nitrate accumulation in unleached soils and the check yield in all experiments. This was true for both methods of incubation when soils were unleached. There was a significant negative correlation between nitrate accumulation and response to nitrogen fertilization in the first experiment. In subsequent experiments there was also a negative correlation, however not always a statistically significant one. The lack of significant correlation between certain responses to fertilizer and nitrification in the second experiment may be due to the absence of much residual effect from fertilizer applied previously in the first experiment. No fertilizer was applied in the second experiment. In experiment No. 4 with the same soils, the lack of significant correlation might be due to the fact that almost all the soils had reached a low level of active organic matter. If so, they responded uniformly to the nitrogen fertilizer although originally the rate of nitrification was different. The nitrate accumulation in leached soils was also negatively correlated with the response to nitrogen fertilization in the first experiment but the correlation was not significant. These results differ with those of Harmsen and Lindenberg (op.cit.) who have recommended the removal of available nitrogen from the soil before conducting a nitrification test. Hanway and Dumenil (op.cit.) have also reported a significant correlation between nitrate accumulation and crop response to fertilizer when soils were leached prior to incubation. However, nitrate accumulation in the leached soil has a significant positive correlation with check yields of experiments No. 1, 2, and 3; although r values obtained were lower than in the unleached soils.

TABLE XIX. Correlations Between Greenhouse Yields and Nitrate-Nitrogen Accumulation

Greenhouse yields (1)	NO_3 - N accumulation (1) Unleached 2 weeks at 28°C.	Unleached 4 weeks at 15°C.	Leached 4 weeks at 15°C.
First Crop (With N applied)			
Check yield	+.546**	+.597**	+.545**
Yield increase with 30 lb.N/A.	-.432**	-.398**	-.139
" " " 60 lb.N/A.	-.497**	-.434**	-.196
" " " 120 lb.N/A.	-.453**	-.429**	-.167
Check yield / Yield with 60 lb.N x 100	+.586**	--	--
Second Crop (Residual effect of N)			
Check yield	+.801**	+.714**	+.521**
Yield increase with 30 lb.N/A.	-.144	--	--
" " " 60 lb.N/A.	-.146	--	--
" " " 120 lb.N/A.	-.301*	-.301*	--
Third Crop (With N applied)			
Check yield	+.654**	+.626**	+.570**
Yield increase with 30 lb.N/A.	-.230	--	--
" " " 60 lb.N/A.	-.400**	-.325*	--
" " " 120 lb.N/A.	-.381**	-.285*	--
Fourth Crop (With N applied)			
Check yield	+.659**	+.621**	--
Yield increase with 120 lb.N/A.	-.184	--	--
" " " 240 lb.N/A.	-.125	--	--
" " " 480 lb.N/A.	-.186	--	--
Fifth Crop (30 soils) (Residual effect of N)			
Check yield	+.437*	+.412*	--
Yield increase with 120 lb.N/A.	+.063	--	--
" " " 240 lb.N/A.	-.011	--	--
" " " 480 lb.N/A.	-.165	--	--

* r value significant at 5 per cent level.

** r value significant at 1 per cent level.

(1) Greenhouse yields given in Table XVII, and nitrate-nitrogen accumulation given in Table XVI.

Although correlation coefficients between nitrate accumulation in unleached soils and some of the yield data from the greenhouse experiments are highly significant, coefficients of determination (r^2) are low. Two possible causes for these low r^2 values are proposed. One of these is differences in the kind of organic matter or its state of decomposition in the soils. This possibility was investigated by calculating the correlation coefficient between nitrate accumulation in 20 soils, selected because of their relatively high rate of mineralization of organic matter, and their check yields. Table XX shows the percentages of total nitrogen mineralized in all 50 soils. The 20 soils chosen were those having a mineralization rate of two per cent or more. For their mineralization rates and first crop check yields, see Tables XX and XVII (A), respectively. The r value was +0.433 and this is a poorer correlation than the one obtained when all 50 soils were taken into consideration. However, those soils which had less than two per cent of their nitrogen mineralized gave a very high r value (+.690**). This indicates that the r^2 values are likely to be higher when soils having low rates of mineralization of nitrogen are taken together than when soils having high rates of mineralization of nitrogen are considered. Another possible cause of the low r^2 values in the first experiment would be the different amounts of nitrate initially present in these soils. The soils which had moderate amounts of nitrate at the start of the experiment might have produced rather good yields in spite of their low nitrifying capacities. This possibility is supported by experiments No. 2 and 3 where higher correlation values were obtained between check yields and nitrate accumulation than were obtained in the first experiment.

There may be a number of other reasons for low r^2 values. The soils collected belong to different zones so they are likely to differ in

TABLE XX. Percentage of Total Soil Nitrogen Converted to Nitrate-Nitrogen

(Note: Unleached soil incubated at 15°C. for 4 weeks)

Soil No.	%
Black Zone	
S- 1	1.29
S- 2	1.13
S- 3	0.64
S- 4	0.92
S- 5	2.04
S- 6	2.02
S- 7	1.55
S- 8	1.42
S- 9	1.00
S-10	1.60
S-11	1.17
S-12	1.18
Thin Black Zone	
S-13	2.42
S-14	2.35
S-15	2.27
S-16	1.55
S-17	1.42
S-18	2.26
S-19	1.96
S-20	1.39
Degraded Black Zone	
S-21	2.41
S-22	0.90
S-23	2.19
S-24	3.03
S-25	3.16
S-26	1.46
S-27	1.54
Grey Wooded Zone	
S-28	1.06
S-29	1.34
S-30	1.48
S-31	1.04
S-32	1.69
Dark Brown Zone	
S-33	1.46
S-34	2.16
S-35	1.56
S-36	1.60
S-37	1.65
S-38	1.49
S-39	1.54
S-40	1.61
S-41	2.10
S-42	2.53
S-43	2.16
Brown Zone	
S-44	6.18
S-45	2.08
S-46	2.50
S-47	2.28
S-48	2.30
S-49	1.64
S-50	3.26

their nitrogen availability. It was not possible to make correlation studies according to zones as the number of soil samples collected was limited. The greenhouse yields may have been affected by factors other than the availability of nitrogen in the soil. Waksman (op.cit.), while discussing the importance of nitrification, has stated that soil fertility is affected not only by the biological activities of the soil but also by its physical and chemical conditions. He considers that the results of a nitrification test can not be expected to be a mathematical function of the productivity of a given soil.

Correlation coefficients between nitrate accumulation and field yields with and without phosphate applications are given in Table XXI. Only soils from 1955 and 1956 field experiments were taken into consideration except for soil S-23 on which a trial was placed in 1954. This was included by mistake. It will be observed that there is no significant relationship when no phosphate was used. There may be a number of reasons for this. The fields from which soil samples were collected differed, some being fallow while others were under the first or second crop after fallow. The quantity of straw present as trash cover also differed appreciably. The soils studied varied widely in their characteristics being from different soil zones. The designs of the field experiments might not have overcome the inherent heterogenity in the soils in all cases. This might have partly masked the effects of nitrogen fertilizer. At each location the experiment was conducted for only one year. It may be that the climatic factors involved were abnormal. To overcome seasonal variations field experiments need to be repeated for at least three years as a general rule.

The relationship might be insignificant because the responses of the crops to nitrogen fertilizer might have been limited by lack of a

TABLE XXI. Correlations Between Field Yields and Nitrate-Nitrogen Accumulation

Field yields (1)	NO_3 - N accumulation (1)		
	Unleached		Leached
	2 weeks at 28°C.	4 weeks at 15°C.	4 weeks at 15°C.
Without Phosphorus			
Check yield	+.100 (2)	+.185	+.228
Yield increase with 33 lb. or less N/A.	-.016	-.059	+.143
Yield increase with more than 33 lb. N/A. (usually 67 lb.)	-.250	-.105	-.016
With Phosphorus at 20 lb. P_2O_5 /A.			
Check yield	+.158	---	---
Yield increase with 33 lb. or less N/A.	-.237	---	---
Yield increase with more than 33 lb. N/A. (usually 67 lb.)	-.320	---	---
$\frac{\text{Yield with 20 lb. } P_2O_5\text{/A.}}{\text{Yield with P + N (67 lb.)}} \times 100$	+.334	---	---

(1) Field yields are given in Table XVIII and nitrate-nitrogen accumulations are given in Table XVI.

(2) r value

sufficient phosphorus supply. To verify this point, the data from the 21 field experiments (Table XVIII) in which the effect of nitrogen in presence of phosphorus are reported were correlated with nitrate accumulation The correlation coefficients for these fields are also given in Table XXI. The relationship again showed no significant correlation. However, the values of r were a little better than in the case of the effect of nitrogen alone on the crop yield. This suggests that a closer relationship between crop yield and nitrate accumulation may be expected if the limiting effect of phosphorus is removed. These results are inconclusive as far as the relationships of nitrate accumulation and field data are concerned because a large variety of factors affected the responses of the fields to the nitrogen application.

The field results discussed in the foregoing do not agree with the findings of some investigators (18, 41, 72, 127, 139). However, results similar to those obtained by the writer have been reported by certain other workers (2, 84, 86, 88). The correlation coefficient between nitrate accumulation and the check yield in the first greenhouse experiment is similar to the one reported by Cook et al. (op.cit.).

In general, it may be concluded that the nitrification test offers good possibilities of its being used in evaluating the fertilizer requirements of soils. Nitrate accumulation in unleached soils is highly correlated with crop yields in the greenhouse experiments. In the writer's opinion, there is every liklihood of nitrate accumulation being significantly correlated with the field yields, particularly if a large number of field trials are conducted under similar cropping and management practices. When data from a large number of tests are available, it might be better to compare field data with nitrate accumulation on a zonal basis.

Effect of leaching the soils on their rate of nitrification was variable (see Table XVI). In 38 out of 50 soils the rate of nitrification increased after leaching. The increased nitrification in leached soils might be due to two reasons. The absence of nitrate-nitrogen after leaching might have increased the activity of the ammonifiers and nitrifiers. This increased activity of the ammonifiers and nitrifiers could be compared with increased nitrogen fixation by Rhizobia in the absence of fertilizer nitrogen. The removal of water soluble toxic substances from the soil (1) by leaching might be another possible explanation. The decrease in nitrification after leaching in a few soils might be due to the removal of available nutrients in the absence of which the microorganisms could not function efficiently. From these Alberta data, one might conclude that in general after leaching a soil, its rate of nitrification increases.

b. Nitrate initially present and per cent mineralization of total nitrogen

Two other aspects of the problem were investigated. First, nitrate nitrogen initially present in the soil (Table XVI) was correlated with the check yield of the first and second greenhouse experiments (Tables XVII A and XVII B) and r values obtained were +.474** and +.704** respectively. The relationship suggests that the determination of available nitrate-nitrogen in the soil may in certain cases be a useful guide to the availability of nitrogen present in a soil. The correlation coefficients obtained between initial nitrate-nitrogen and check yields were not as high as the ones for nitrate-nitrogen accumulation in unleached soils. The second aspect investigated concerned the mineralization of soil nitrogen. Correlation coefficients between per cent nitrogen mineralized to nitrates (Table XX) and check yields in the first and second greenhouse experiments were +.497** and +.312* respectively. These values are significant but they are lower

than those obtained with nitrate-nitrogen accumulation. It seems that the method suggested by both Woodruff (op.cit.) and Smith (142) for calculating the nitrogen requirements of crops based merely on the empirical values of total nitrogen becoming available in different soils may not hold good under Alberta conditions. Thus, while the two tests, nitrate-nitrogen initially present and the percentage of total nitrogen mineralized, are significantly correlated with the check yield of the first and second greenhouse experiments, the correlation values were lower than the ones obtained with nitrate accumulation.

c. Wisconsin method for available nitrogen

As previously stated, Truog et al. at Wisconsin have developed a test for estimating the nitrogen requirements of soils. The test was made on the fifty Alberta soils. The available nitrogen values obtained by the test and by a modification of it are given in Table XXII. The relationships of the available nitrogen values thus determined to yields obtained in greenhouse and field experiments are given in Table XXIII. Examining first the correlations with the first greenhouse experiment, we see that the check yields are significantly correlated with the available nitrogen determined by the above stated two methods. Increases in yield, however, are significantly correlated only with the unmodified method. The correlation coefficients for subsequent experiments were calculated, therefore, taking available nitrogen determined by the Wisconsin method only into consideration. The overall results indicate that the correlation values between available nitrogen and check yield increase with the number of crops.

Looking at the correlation coefficients between available nitrogen determined by the Wisconsin method and field yields, it is observed

TABLE XXII. Available Nitrogen by the Wisconsin and the Modified Wisconsin Methods

Soil No.	Available N lb./A. Wisconsin method	Modified method
Black Zone		
S- 1	226	245
S- 2	243	264
S- 3	172	275
S- 4	264	258
S- 5	291	322
S- 6	333	302
S- 7	255	275
S- 8	200	236
S- 9	307	287
S-10	268	326
S-11	220	186
S-12	254	275
Thin Black Zone		
S-13	356	359
S-14	151	257
S-15	285	226
S-16	300	376
S-17	216	276
S-18	162	243
S-19	228	339
S-20	214	269
Degraded Black Zone		
S-21	252	162
S-22	111	178
S-23	130	193
S-24	172	248
S-25	152	177
S-26	192	188
S-27	194	216
Grey Wooded Zone		
S-28	233	215
S-29	98	178
S-30	248	185
S-31	164	172
S-32	172	234
Dark Brown Zone		
S-33	231	273
S-34	233	230
S-35	281	285
S-36	182	313
S-37	179	297
S-38	222	310
S-39	226	276
S-40	111	188
S-41	166	235
S-42	134	218
S-43	148	215
Brown Zone		
S-44	236	289
S-45	109	201
S-46	154	233
S-47	138	205
S-48	177	319
S-49	256	301
S-50	156	179

TABLE XXIII. Correlation Between Yields and the Wisconsin Method Data

Yields (1)	Available nitrogen by: (1) Wisconsin method	Modified Wisconsin method
A. Greenhouse		
First Crop:		
Check yield	+.308*	+.349*
Yield increase with 30 lb. N/A.	-.392**	-.154
" " " 60 lb. N/A.	-.513**	-.274
" " " 120 lb. N/A.	-.396**	-.168
Second Crop:		
Check yield	+.703**	---
Yield increase with 30 lb. N/A.	-.090	---
" " " 120 lb. N/A.	-.355*	---
Third Crop:		
Check yield	+.681**	---
Yield increase with 60 lb. N/A.	-.350*	---
" " " 120 lb. N/A.	-.437**	---
Fourth Crop:		
Check yield	+.748**	---
Fifth Crop:		
Check yield (30 soils)	+.619**	---
B. Field		
Check yield	+.267	---
Yield increase with 33 lb. or less N/A.	+.003	---
Yield increase with more than 33 lb. N/A. (usually 67 lb.)	-.0004	---

(1) Greenhouse and field yield data given in Tables XVII and XVIII, respectively; available nitrogen data given in Table XXII.

* r value significant at 5 per cent level.

** r value significant at 1 per cent level.

that none of the coefficients are significant. However, Truog et al. (op.cit.) have stated that the method is quite useful in making nitrogen fertilizer recommendations in Wisconsin. The method may be applicable under Alberta field conditions when calibrated with the field responses obtained from carefully controlled experiments.

Available nitrogen values by the Wisconsin method were significantly correlated with nitrate accumulation in unleached soils, r equalling +.774.

These studies indicate, therefore, that available nitrogen values determined by the Wisconsin method are significantly correlated with most of the greenhouse yields but not with the field yields. Although the correlation values obtained are generally lower than with the nitrate accumulation, the test has the advantages of being quick and simple with no special equipment required. When properly calibrated with field data, the test may be useful for advisory purposes.

d. Total nitrogen in soils

Data for total nitrogen in the soils are given in Table XV. No significant correlation (r = +.154) was found between nitrogen content of the soils and their check yield in the first greenhouse experiment. Its relationship to subsequent crops was, therefore, not calculated. The nitrogen content of the soils was, however, significantly correlated with nitrate accumulation and also with available nitrogen as determined by the Wisconsin method. The r values obtained were +.602** and +.768**, respectively. Subbiah and Asija (156) have also reported a significant correlation between total nitrogen and available nitrogen determined by a modified Wisconsin method. It seems the determination of total nitrogen in the soil for estimating nitrogen fertilizer requirements is of little use under Alberta conditions.

e. Nitrogen in plant material

Table XXIV presents data for nitrogen content of unfertilized oat plants from the first experiment. The correlation coefficient ($r = +.099$) between these values and the check yields in the first greenhouse experiment (Table XVII A) was not significant. Under conditions of this experiment the results were different to those of Macy (op.cit.) who found a definite relationship between the nitrogen content of a crop and its yield. In the light of these conflicting results it would seem unwise to use percentage total nitrogen in plant material as a guide to nitrogen requirements. The use of nitrate-nitrogen percentages is another matter, and as indicated in the review of literature has been studied by other workers.

f. 'N' values

As already stated under materials and methods, the 'N' value of a soil is determined by finding the nitrogen uptake by a crop under different treatments of nitrogen. Nitrogen uptake by oats under four levels of nitrogen in the first greenhouse experiment were determined for each soil and are given in Table XXV along with data for percentage utilization of fertilizer nitrogen. The values for 'N' calculated from the nitrogen uptake data for the fifty soils are given in Table XXVI. In soil No. S-6, the 'N' value calculated was invalid as the nitrogen uptake dropped with increased nitrogen application. In four other soils, No. S-5, S-7, S-13, and S-44, the 'N' values obtained were extraordinarily high.

Correlation coefficients between 'N' values and some other data are given in Table XXVII. Significant negative correlations were found between 'N' values and responses to nitrogen in the first greenhouse experiment; that is, soils with the lower 'N' values showed greatest increases from application of nitrogen. There were no significant correlations between

TABLE XXIV. Nitrogen Content of Plant Material from Unfertilized Treatment of Greenhouse Experiment No. 1

Soil No.	% N
Black Zone	
S- 1	1.76
S- 2	1.79
S- 3	1.68
S- 4	1.72
S- 5	2.36
S- 6	2.35
S- 7	2.17
S- 8	1.48
S- 9	2.06
S-10	1.59
S-11	1.83
S-12	1.79
Thin Black Zone	
S-13	2.40
S-14	1.87
S-15	1.85
S-16	1.92
S-17	1.35
S-18	1.39
S-19	1.55
S-20	1.55
Degraded Black Zone	
S-21	1.86
S-22	1.37
S-23	2.04
S-24	1.54
S-25	1.36
S-26	1.91
S-27	2.02
Grey Wooded Zone	
S-28	1.70
S-29	1.87
S-30	1.85
S-31	1.82
S-32	1.70
Dark Brown Zone	
S-33	1.85
S-34	2.00
S-35	1.65
S-36	1.52
S-37	1.61
S-38	1.66
S-39	1.33
S-40	1.13
S-41	1.31
S-42	1.50
S-43	1.41
Brown Zone	
S-44	2.35
S-45	1.23
S-46	1.34
S-47	1.19
S-48	1.36
S-49	1.68
S-50	1.40

TABLE XXV. Nitrogen Uptake and Percentage Utilization of Fertilizer Nitrogen in Experiment No. 1

Soil No.	N uptake in mg. when N applied at: 0 lb./A.	30 lb./A.	60 lb./A.	120 lb./A.	Per cent utilization of N applied at: 30 lb./A.	60 lb./A.	120 lb./A.
Black Zone							
S- 1	36	44	51	53	30 (1)	29	16
S- 2	40	50	55	69	38	28	27
S- 3	21	31	36	45	36	28	22
S- 4	36	45	56	65	34	36	26
S- 5	38	41	44	44	10	11	6
S- 6	61	61	61	60	0	0	0
S- 7	60	57	60	66	0	1	5
S- 8	35	48	60	78	49	47	40
S- 9	46	56	60	81	38	26	32
S-10	39	52	58	72	48	36	31
S-11	42	50	61	66	28	34	22
S-12	32	43	52	66	43	38	32
Thin Black Zone							
S-13	68	74	73	75	21	10	6
S-14	41	49	58	65	27	31	22
S-15	41	50	52	66	35	22	14
S-16	44	51	56	63	23	21	17
S-17	28	41	50	61	47	39	30
S-18	29	41	50	60	42	39	28
S-19	47	56	70	90	36	43	40
S-20	27	39	--	51	43	--	22
Degraded Black Zone							
S-21	40	47	55	63	25	28	21
S-22	18	32	43	58	50	44	36
S-23	31	40	46	53	32	27	20
S-24	42	51	65	82	32	43	36
S-25	30	44	57	72	53	50	39
S-26	36	41	51	57	20	29	25
S-27	39	49	56	66	38	31	25

(Continued on next page)

TABLE XXV. Nitrogen Uptake and Percentage Utilization of Fertilizer Nitrogen in Experiment No. 1 (Continued)

Soil No.	N uptake in mg. when N applied at: 0 lb./A.	30 lb./A.	60 lb./A.	120 lb./A.	Per cent utilization of N applied at: 30 lb./A.	60 lb./A.	120 lb./A.
Grey Wooded Zone							
S-28	32	41	52	61	32	36	26
S-29	34	42	49	54	30	28	18
S-30	45	54	61	72	35	30	25
S-31	37	43	51	61	20	25	22
S-32	40	50	58	71	36	33	28
Dark Brown Zone							
S-33	34	44	52	62	35	33	26
S-34	48	55	65	74	26	31	23
S-35	40	52	58	75	46	34	32
S-36	32	42	51	58	36	34	24
S-37	34	39	53	68	20	35	31
S-38	42	50	56	69	26	26	25
S-39	34	49	58	77	54	43	39
S-40	24	36	50	70	45	48	42
S-41	28	43	52	67	56	46	36
S-42	26	37	48	51	41	40	23
S-43	43	59	64	87	56	38	40
Brown Zone							
S-44	78	83	86	89	19	16	11
S-45	21	33	48	71	42	49	46
S-46	36	47	56	67	41	37	29
S-47	24	34	49	63	37	45	35
S-48	41	51	58	74	35	31	30
S-49	37	47	54	71	37	31	31
S-50	33	44	54	70	42	39	34

(1) Calculated thus: $\frac{\text{N uptake with 30 lb. N} - \text{N uptake with 0 lb. N}}{\text{N added as fertilizer}} \times 100$

TABLE XXVI. The 'N' Values for the Fifty Soils

(Note -- Based on experiment No. 1 data)

Soil No.	'N' value
Black Zone	
S- 1	281
S- 2	174
S- 3	121
S- 4	160
S- 5	733
S- 6	---
S- 7	989
S- 8	102
S- 9	163
S-10	153
S-11	220
S- 12	117
Thin Black Zone	
S-13	1536
S-14	215
S-15	210
S-16	295
S-17	119
S-18	127
S-19	126
S-20	155
Degraded Black Zone	
S-21	216
S-22	64
S-23	188
S-24	127
S-25	95
S-26	196
S-27	189
Grey Wooded Zone	
S-28	141
S-29	226
S-30	207
S-31	189
S-32	164
Dark Brown Zone	
S-33	156
S-34	228
S-35	146
S-36	163
S-37	112
S-38	192
S-39	104
S-40	64
S-41	97
S-42	148
S-43	128
Brown Zone	
S-44	843
S-45	50
S-46	147
S-47	78
S-48	158
S-49	138
S-50	112

TABLE XXVII. Correlations Between Yields, Nitrate-Nitrogen Accumulation, and 'N' Values

Correlation between 'N' values and	d.f.	r value
Yield without nitrogen in first greenhouse expt. (45 soils) (1)	43	+.095
Yield increase with 30 lb. N/A. in first greenhouse expt. (45 soils)	43	-.727**
Yield increase with 60 lb. N/A. in first greenhouse expt. (45 soils)	43	-.754**
Yield increase with 120 lb. N/A. in first greenhouse expt. (45 soils)	43	-.794**
Yield increase with 33 lb. or less N/A. in field expt.	29	-.257
NO_3-N accumulation in unleached soils in 2 weeks at 28°C.	43	+.518**

(1) Soils S-5, S-6, S-7, S-13, and S-44 excluded because N values unusually high.

** Significant at 1 per cent level.

'N' values and check yields. No significant correlation was found between 'N' values and increase in yields in the field with the 33 lb. rate of nitrogen per acre. The 'N' values were significantly correlated with nitrate-nitrogen accumulation. These findings indicate that values of 'N' have higher r values when correlated with increases in yield both in greenhouse and field experiments than were found when the latter were correlated with either nitrate-nitrogen accumulation or with available nitrogen determined by the Wisconsin method. It may be concluded that the 'N' values offer a greater possibility of estimating nitrogen fertilizer responses than other tests for these soils. However, the procedure for the determination of 'N' value for a soil is quite lengthy and laborious, and requires greenhouse facilities.

g. Nitrogen uptake as related to selected tests

The comparative value of some of the tests was further studied by comparing their relationship with the nitrogen uptake under the check treatment of the first greenhouse experiment. The data for the nitrogen uptake were given in Table XXV, and these were correlated with 'N' values, with NO_3-N accumulation data, and with available nitrogen by the Wisconsin method. Correlation coefficients found are given in Table XXVIII. The highest correlation was found with nitrate-nitrogen accumulation suggesting that nitrate accumulation was the best test for predicting the availability of nitrogen and hence uptake by the crop. Note however, that high uptake does not necessarily mean high yield.

TABLE XXVIII. Correlations Between Nitrogen Uptake by Unfertilized Plants of the First Crop and Some Other Data

Relationship between nitrogen uptake and	r value
'N' values (45 soils)	.632**
NO_3-N accumulation in unleached soils in 2 weeks at 28°C.	.830**
Available nitrogen by the Wisconsin method	.623**

** Significant at 1 per cent level.

On the basis of the results discussed above for evaluating the different nitrogen tests as a means of estimating the nitrogen requirements of some Alberta soils, it may be concluded that:

1. The determinations of total nitrogen in the soil and in the plant material are of little value.
2. The determinations of nitrate-nitrogen initially present in the soil and the per cent of nitrogen mineralized were found to be significantly correlated with some of the greenhouse yield data. Their r values were, however, lower than for the nitrate accumulation test.
3. The determination of available nitrogen by the Wisconsin method offers good possibilities of being used. The method is quite rapid and simple.
4. 'N' values showed significant correlations with responses in the greenhouse. The correlation of 'N' value with nitrogen response in the field experiment, though not significant was better than with other tests. The method has the drawbacks of being lengthy and laborious.
5. Of the methods tested, the nitrate accumulation in unleached soils when incubated for two weeks at 28°C. seems to be the most promising one. It is simple and not very lengthy. The correlation values obtained by this test were either better or compared favourably with the other tests.
6. None of the tests was found to be significantly correlated with field yields.

C. Relationship of Nitrate-Nitrogen Accumulation to 1957 Trials

In order to evaluate further the nitrate-nitrogen accumulation test, its relationship to field data obtained in 1957 trials was studied. The field data were divided into two categories. One category included those fields where nitrogen was applied to apparently nitrogen deficient

crops; the other category included other field trials on small plots and long strips where nitrogen was applied. Details of these trials are given in the Fertilizer Experiment Report for 1957 prepared by the Department of Soil Science, University of Alberta (op.cit.). There were 35 and 19 trials respectively in the two categories. The nitrate-nitrogen accumulation in the soils and the yield data are given in Tables XXIX and XXX. Correlation coefficients between nitrate-nitrogen accumulation and field data are given in Table XXXI.

These results indicate that in the first category, the 35 soils, the nitrate-nitrogen accumulation is positively correlated at the 1 per cent level with the check yields. It should be noted that the trials on these 35 soils were very carefully placed on selected sites where nitrogen deficiencies were showing conspicuously. These trials were in addition on small areas. The high positive correlation, therefore, between nitrate accumulation and check yield might have been expected and the study shows the value of the nitrate-nitrogen accumulation test in assessing productive capacity under carefully controlled test conditions. In the second category no such correlation was found between nitrate accumulation and check yields. This is undoubtedly due to the variability in the soils, sites, and test conditions of the 19 trials reported.

The correlation coefficients where nitrogen fertilizer was applied appear at first sight out of line with expected results. In the first category one might have expected significant negative correlations between nitrate accumulation and yield increases with nitrogen fertilizer. Such was not the case. This anomaly is explained in part in the Fertilizer Report by the delay in maturity and consequent shrinkage on harvesting of the plots receiving high rates of nitrogen application. In the second category negative correlations between yield increases with only nitrogen fertilizer and

TABLE XXIX. Nitrate-Nitrogen Accumulation and Yield Data for the 35 Soils (1)

Univ. Trial No.	NO_3-N p.p.m. accumulation in 2 weeks at 28°C.(2)	Check yield cwt./A.	Yield increases in cwt. with N per acre applied at: 20 lb.	40 lb.	60 lb.
Black Zone					
U19- 4	43	8.4	7.4	8.7	10.9
U19- 5	40	8.8	0.7	1.8	1.3
U19- 8	55	12.9	3.9	6.7	4.7
U19-10	103	14.6	2.4	4.5	4.6
U19-11	41	8.3	2.6	3.1	4.7
U19-16	54	8.9	1.3	2.2	0.0
U19-17	84	18.5	1.7	5.5	3.7
U19-19	57	11.7	5.1	5.4	6.5
U19-23	54	8.4	5.2	-0.5	7.1
U19-24	64	12.0	-0.5	-1.8	3.6
U19-25	48	9.2	-0.1	0.1	-1.1
U19-29	64	14.2	1.7	1.2	2.3
U19-32	54	5.5	8.7	6.1	4.2
U19-37	55	8.9	0.4	3.6	4.7
U19-40	74	12.6	1.9	5.4	10.8
U19-44	81	25.8	-0.3	-1.3	2.1
U20- 7	45	11.0	3.2	2.4	4.7
U20-26	55	18.6	4.1	6.7	8.9
U20-45	73	22.0	5.5	5.7	8.2
Degraded Black Zone					
U19- 1	35	6.2	1.8	1.1	1.4
U19- 3	69	8.3	1.3	2.8	5.9
U19-14	48	7.5	1.7	2.5	4.1
U20-18	36	8.6	1.1	1.7	4.1
U20-22	41	12.9	1.8	7.9	4.5
U20-28	53	5.0	2.4	2.4	3.0
U20-30	41	7.2	1.8	2.2	1.5
U20-33	42	11.9	2.9	5.1	4.9
U20-38	62	9.0	1.9	1.1	5.0
U20-42	89	10.1	2.5	3.3	2.6
U20- 2	54	4.7	6.3	5.3	11.6
U20- 6	66	9.4	1.1	7.0	6.3
U20-15	45	6.1	1.6	1.6	1.4
U20-31	42	12.7	2.1	2.9	4.3
Grey Wooded Zone					
U20-13	52	11.9	3.5	0.1	5.2
U20-12	57	7.8	5.9	2.8	4.8

(1) These trials were conducted by Mr. D. K. McBeath in 1957. Yield data from bushels converted to hundredweights.

(2) These figures represent increase in NO_3-N over and above amounts initially present.

TABLE XXX. Nitrate-Nitrogen Accumulation and Yield Data for the 19 Soils (1)

Univ. Trial No.	NO_3-N p.p.m. accumulation in 2 weeks at 28°C.(2)	Fertilizers used per acre: No P_2O_5 applied — No N Yield in cwt.	N @ 20 Increases in cwt.	N @ 40 Increases in cwt.	20 lb. P_2O_5 applied — No N Yield in cwt.	N @ 20 Increases in cwt.	N @ 40 Increases in cwt.
Black Zone							
U16-11	54	16.0	4.5	9.5	16.8	1.8	12.9
U13- 7	161	2.0	0.3	-0.5	10.0	1.9	3.5
U13- 2	86	19.0	-0.8	-1.4	20.3	-0.4	-3.7
U13- 4	87	4.5	-0.4	-1.5	8.7	2.3	1.7
Thin Black Zone							
U16-10	92	14.2	-0.8	-1.0	15.8	1.9	1.1
Degraded Black Zone							
U15- 1	53	14.7	-0.6	0.1	17.0	-0.9	-1.2
U15-14	44	11.6	2.2	3.5	13.0	2.8	3.7
U15-12	47	7.4	4.3	6.4	8.8	2.8	4.8
U15- 7	109	1.8	0.3	0.7	1.8	0.1	2.1
U15- 2	64	16.3	0.3	-0.4	17.0	2.7	3.2
U15- 5	72	12.9	3.8	3.7	15.6	5.1	5.3
U15-15	97	8.8	-0.9	3.5	12.6	4.2	9.1
U15-17	73	14.8	1.6	2.0	16.0	2.5	3.8
U15- 9	42	8.6	2.9	3.1	11.1	6.1	4.5
Grey Wooded Zone							
U15-13	49	7.3	1.6	0.9	7.6	2.3	2.1
U15- 3	61	8.0	2.0	2.9	12.9	0.3	0.7
U15- 8	79	3.7	1.7	1.8	4.5	1.5	3.0
Dark Brown Zone							
U13- 3	90	15.8	-2.3	-2.6	18.5	-7.3	-7.3
U13- 6	55	8.3	-0.6	0.8	13.9	0.8	3.8

(1) These trials were conducted by the Soil Science Department in 1957. Yield data from bushels converted to hundredweights.

(2) These figures represent increase in NO_3-N over and above amounts initially present.

TABLE XXXI. Correlations Between Nitrate-Nitrogen Accumulation and the Field Yields, 1957

Relationship between NO_3-N accumulation in 2 weeks at 28°C. and	D. F.	r value
A. Tests on 35 nitrogen deficient crops		
Check yield	33	+.517**
Yield increase with 20 lb. N/A.	33	-.073
Yield increase with 40 lb. N/A.	33	+.051
Yield increase with 60 lb. N/A.	33	+.127
B. Field trials on small plots and long strips		
Check yield	17	-.333
Yield increase with 20 lb. N/A.	17	-.466*
Yield increase with 40 lb. N/A.	17	-.449
Yield with 20 lb. P_2O_5/A.	17	-.180
Yield increase with 20 lb. N/A. over phosphorus treated	17	-.201
Yield increase with 40 lb. N/A. over phosphorus treated	17	-.153

* r value significant at 5 per cent level.
** r value significant at 1 per cent level.

nitrate-nitrogen accumulation are noteworthy. Why the addition of phosphate fertilizer upsets this relationship is difficult to explain. As already stated, the relationship of nitrate-nitrogen accumulation to field data might be better if a larger number of well designed experiments were conducted for a number of years in each zone.

D. Recovery of Fertilizer Nitrogen in the Greenhouse Experiments

Data for recovery of fertilizer nitrogen added to soils in the first greenhouse experiment were given in Table XXV. Data for the remaining experiments are given in Tables XXXII (A), XXXII (B), and XXXII (C). Examination of these tables leads to the following conclusions.

1. The first experiment showed a decreasing percentage utilization of nitrogen with increasing rate of application. In this experiment 30 to 40 per cent of fertilizer nitrogen added at the rates of 30 lb. and 60 lb. per acre was recovered. Its recovery was only 20 to 30 per cent when applied at the rate of 120 lb. nitrogen per acre.
2. In the second experiment 5 to 10 per cent of fertilizer nitrogen was recovered under the treatments of 30 and 60 lb. nitrogen per acre. The recovery was higher however under the treatment of 120 lb. nitrogen per acre, 15 to 20 per cent being the range.
3. It appears that most of the nitrogen added at rates of 30 and 60 lb. per acre and not utilized by the first crop was lost in some way, either by immobilization or by volatilization. In the case of the highest rate of application, some of the nitrogen was available for the subsequent crop.
4. In five soils, S-5, S-6, S-7, S-13, and S-44, which have comparatively high rates of nitrification and high 'N' values, the recovery of nitrogen added was markedly lower than with other soils. This was to be expected since these soils are rich in nitrogen and show little response to fertilization.

TABLE XXXII (A). Percentage Utilization of Fertilizer Nitrogen in Greenhouse Experiments

Soil No.	Experiment No. 2 N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	Experiment No. 1 and 2 combined N applied at: 30 lb./A.	60 lb./A.	120 lb./A.
S- 1	8.1	15	30	38	44	46
S-10	12	13	18	60	49	48
S-16	8.1	10	24	31	31	41
S-17	0.7	5.0	11	48	44	41
S-18	9.5	4.8	13	52	43	41
S-19	5.9	5.3	15	50	51	52
S-24	13	12	13	45	55	49
S-30	19	13	22	54	43	47
S-31	0.0	4.8	23	20	30	44
S-35	21	13	15	66	47	47
S-36	5.9	5.3	15	42	39	38
S-37	4.0	7.5	15	24	42	46
S-38	7.3	10	17	34	36	42
S-39	10	3.5	8.0	64	47	47
S-40	4.4	5.9	5.1	50	54	47
S-43	11	4.0	7.7	67	42	48
S-45	0.4	2.2	4.6	43	51	50
S-47	1.8	5.3	6.1	39	51	42
S-48	0.0	6.6	12	35	37	42
S-49	9.9	15	18	47	45	48

TABLE XXXII (B). Percentage Utilization of Fertilizer Nitrogen in Greenhouse Experiments

Soil No.	Experiment No. 3 N applied at: 30 lb./A.	60 lb./A.	120 lb./A.	Soil No.	Experiment No. 4 N applied at: 120 lb./A.	240 lb./A.	480 lb./A.
S- 1	60	63	49	S- 2	43	45	31
S-10	64	57	46	S- 3	45	37	23
S-16	48	47	41	S- 4	49	47	28
S-17	48	39	39	S- 5	36	39	29
S-18	57	56	52	S- 7	46	50	28
S-19	55	57	47	S-10	41	41	25
S-24	36	49	35	S-12	43	40	26
S-30	43	46	40	S-14	46	40	26
S-31	45	50	48	S-16	46	37	22
S-35	37	43	37	S-17	43	39	27
S-36	56	56	50	S-21	52	40	27
S-37	68	56	54	S-22	50	49	33
S-38	46	43	39	S-25	51	49	30
S-39	42	48	45	S-26	40	32	24
S-40	52	45	50	S-28	45	40	24
S-43	42	51	51	S-29	39	41	27
S-45	48	49	48	S-30	46	37	21
S-47	35	41	43	S-31	37	33	24
S-48	47	55	50	S-32	44	41	28
S-49	49	56	45	S-33	40	39	26
				S-34	49	43	30
				S-35	55	38	33
				S-36	47	47	32
				S-38	43	41	22
				S-39	44	46	29
				S-40	45	37	29
				S-41	46	42	28
				S-42	29	33	27
				S-43	53	50	37
				S-48	45	41	29

TABLE XXXII (C). Percentage Utilization of Fertilizer Nitrogen in Greenhouse Experiments

Soil No.	Experiment No. 5 N applied at: 120 lb./A.	240 lb./A.	480 lb./A.	Experiments No. 4 and 5 combined N applied at: 120 lb./A.	240 lb./A.	480 lb./A.
S- 2	3.1	4.4	6.5	46	50	38
S- 3	4.4	5.7	5.0	50	43	28
S- 4	1.6	7.4	7.6	51	54	36
S- 5	1.6	3.7	6.4	37	43	35
S- 7	4.9	6.5	6.7	51	57	35
S-10	4.0	6.6	5.6	45	48	30
S-12	2.9	5.9	6.6	45	46	33
S-14	3.2	5.7	5.4	49	45	32
S-16	6.3	7.7	5.3	52	45	28
S-17	2.2	3.5	5.6	45	42	33
S-21	4.6	4.2	6.4	57	44	34
S-22	3.5	5.4	7.1	54	54	40
S-25	4.6	6.5	7.5	55	55	38
S-26	3.9	4.4	4.9	44	36	29
S-28	5.1	7.4	5.9	50	48	30
S-29	4.4	6.8	5.2	43	48	32
S-30	5.0	7.9	6.1	51	45	27
S-31	1.7	7.1	5.9	38	40	30
S-32	3.3	8.3	6.8	48	49	34
S-33	1.7	7.3	6.2	42	46	32
S-34	3.9	7.3	7.1	53	51	37
S-35	6.8	4.0	6.1	61	42	39
S-36	4.4	7.8	10	52	55	42
S-38	4.0	6.2	6.5	47	48	29
S-39	3.1	4.8	6.9	47	51	36
S-40	2.8	4.0	6.9	47	41	36
S-41	3.7	7.0	7.5	49	49	36
S-42	3.4	3.6	7.5	32	37	35
S-43	5.5	6.6	9.6	58	57	47
S-48	-.5	4.6	5.9	44	46	34

5. The addition of perlite to the soil-sand mixture resulted in higher recovery of fertilizer nitrogen judging from the third experiment. Perlite seems to have improved the physical condition of the soil-sand mixture.
6. The recovery of fertilizer nitrogen in the third experiment was 45 to 60 per cent. It was slightly more in the case of the lower levels than in the highest level of nitrogen application.
7. The per cent recovery declined sharply with the high levels of nitrogen used in experiment No. 4. A range of 25 to 45 per cent recovery resulted when nitrogen was applied at 120, 240, and 480 lb. per acre. The higher percentages of recovery was associated with the lower rates of application as before.
8. There was a slight recovery of fertilizer nitrogen in experiment No. 5. It was of the order of 2 to 4 per cent for the treatment of 120 lb. nitrogen per acre and 4 to 8 per cent for the treatments of 240 and 480 lb. nitrogen per acre. It suggests that little fertilizer nitrogen was left in the soil after the removal of one crop, especially under the lowest rate of nitrogen application.
9. The total recovery of fertilizer nitrogen in the fourth and fifth experiments combined was 40 to 55 per cent for lower rates of 120 and 240 lb. nitrogen per acre. At the highest rate of 480 lb. nitrogen per acre the general range of recovery was 30 to 35 per cent.

In general, from 40 to 65 per cent of the fertilizer nitrogen was not recovered in the crops. In an effort to account for this nitrogen, nitrates were determined in some of the soils. These data are given in Table XXXIII. In addition, the nitrifying powers of some of the soils taken from the pots were determined and are given in Table XXXIV.

TABLE XXXIII. Nitrate-Nitrogen in p.p.m. Remaining in Soils After Experiments No. 2 and No. 3

Soil No.	After No. 2 N applied at: 0 lb.	30 lb.	60 lb.	120 lb.	Soil No.	After No. 3 N applied at: 0 lb.	30 lb.	60 lb.	120 lb.
S- 1	0.6	0.6	0.5	0.6	S- 8	0.5	0.5	0.7	3.0
S-10	1.2	1.2	1.3	1.3	S-18	0.8	0.7	0.8	4.6
S-11	2.3	1.5	1.4	2.2	S-21	0.3	0.5	0.0	0.6
S-16	1.1	1.4	1.4	2.3	S-22	0.3	0.2	0.0	0.2
S-17	0.7	0.8	0.7	0.6	S-24	0.4	0.5	0.5	4.4
S-18	0.7	0.7	0.6	0.6	S-35	1.1	1.5	1.8	5.0
S-19	1.7	1.6	1.7	1.8	S-38	0.9	1.3	1.8	5.3
S-24	0.5	0.5	0.3	0.4	S-39	0.6	0.8	1.1	2.2
S-25	0.3	0.5	0.6	0.5	S-42	0.3	0.3	0.1	0.8
S-30	0.7	0.7	1.0	1.4	S-44	0.3	0.3	0.6	1.2
S-31	0.8	0.3	0.3	0.3					
S-35	1.8	2.9	1.6	2.8					
S-36	1.0	1.1	1.0	1.2					
S-37	0.9	0.9	0.8	1.0					
S-38	0.9	1.1	1.2	1.6					
S-39	1.4	1.0	1.1	1.0					
S-40	0.4	0.4	0.3	0.6					
S-41	0.3	0.6	0.7	0.5					
S-43	1.2	1.9	0.6	1.3					
S-44	1.0	1.7	2.1	6.3					
S-45	0.4	0.3	0.7	0.7					
S-47	0.3	0.2	0.2	0.3					
S-48	1.3	1.3	1.2	1.6					
S-49	0.8	0.7	0.6	0.6					
S-50	0.5	0.4	0.4	0.5					

TABLE XXXIV. Nitrate-Nitrogen Production in p.p.m. in Soils on Incubation after Experiment No. 2 and No. 3 (1)

Soil No.	After No. 2 N applied at : 0 lb.	30 lb.	60 lb.	120 lb.	Soil No.	After No. 3 N applied at : 0 lb.	30 lb.	60 lb.	120 lb.
S- 4	41	37	40	44	S- 8	23	24	26	33
S- 9	35	37	41	47	S-18	25	24	26	33
S-13	45	48	50	56	S-21	--	25	29	30
S-32	34	31	36	34	S-22	13	16	15	17
S-33	39	44	36	39	S-24	21	21	24	33
					S-35	31	32	35	41
					S-38	28	26	30	35
					S-39	23	25	26	31
					S-42	18	20	17	21
					S-44	21	20	25	27

(1) The soils were incubated for 2 weeks at 28°C.

These tables lead to the following conclusions.

1. Very little nitrate-nitrogen was found in the soil after growing two crops irrespective of the amount of nitrogen applied to the first crop. There was slightly more nitrate-nitrogen in the soil treated with 120 lb. nitrogen per acre after growing one crop, as indicated after experiment No. 3.
2. There were slightly higher nitrate accumulations in soils treated with fertilizer nitrogen especially after experiment No. 3 and at the highest level of nitrogen application. This increased availability of nitrate-nitrogen might account for the significant increase in yield obtained with 120 lb. nitrogen per acre in the second experiment.
3. The extra nitrate accumulation in fertilized soils was not large compared to the amount not recovered by the plant and therefore unaccounted for. Had the accumulation been large and approaching the amounts not recovered, it would have suggested that the nitrogen was immobilized in the soil and not lost by volatilization. Since this was not the case, it seems probable that nitrogen was lost to the atmosphere in some way.

The nitrogen remaining unaccounted for may be explained in a number of ways. Some fertilizer nitrogen must have been tied up with the increased plant roots in treated pots. This is based on the assumption that increased yield was accompanied by increased root growth. Microorganisms may have incorporated some nitrogen in their bodies. Broadbent and Stojanovic (26) using tagged N^{15} proved that a part of the fertilizer nitrogen was immobilized and converted to microbial protein. Some of the ammonium nitrogen might have been fixed in the soil (5, 155). A portion of the added nitrogen might have been lost through denitrification. It is

well known that under anaerobic conditions denitrification occurs. In recent years several investigators (12, 26, 48, 51, 66, 67, 78, 171, 185) have reported the loss of nitrogen through denitrification under aerobic conditions. In the experiments reported here, the soils were well aerated most of the time though on occasions when watering was done, the aeration was retarded. It seems probable that these aerobic and semi-aerobic conditions might have led to the loss of added nitrogen which was applied in the form of ammonium nitrate. Wijler and Delwiche (185) considered that as a result of alternating aerobic and anaerobic soil conditions the loss of total nitrogen may be greater than would be found under strictly anaerobic conditions. There is little possibility of much nitrogen being lost in the ammonia form as most of these soils were acidic in reaction (105, 151). Fraps and Sterges (59) have suggested that in rare cases nitrites may be formed during the nitrification of ammonium salts and decomposed chemically in acid soils with loss of nitrogen. There was no loss of the fertilizer nitrogen through leaching. The percolation of water was almost completely avoided and in case there was any percolation, the leachate was collected in aluminum plates which were washed back into their respective pots.

In general, about 35 to 60 per cent of fertilizer nitrogen was recovered when added to soils at different rates in the greenhouse. The recovery was a little better at lower rates and also when the physical condition of the soil was improved. The nitrogen unrecovered seems to be lost partly through denitrification. A part of it might have been tied up in increased plant roots. A small proportion might have been immobilized by the microorganism. Some in the ammonium form might have been fixed in the soil.

E. Responses of Soils to Nitrogen Fertilizer

Nitrate accumulation in soils and yield data from the experiments with different levels of nitrogen have already been given in Tables XVI and XVII. Significant yield increases in the first experiment were obtained in soils whose rates of nitrate-nitrogen accumulation were less than 80 p.p.m. when incubated at 28°C. for two weeks. A comparison of Tables XVI and XVII (A) shows that in general unleached and incubated (28°C.) soils producing over 80 p.p.m. of nitrate-nitrogen give an F value for response to fertilizer which is not significant. There were certain soils having nitrate-nitrogen accumulation more than 80 p.p.m. which did respond to the application of nitrogen fertilizer. This suggests that the nitrate production in these soils under greenhouse conditions might have been retarded by the environmental factors in spite of a satisfactory level of mineralizable organic nitrogen (88). There were some other soils such as S-29, S-36, and S-48 which, although having low nitrification rates, did not respond to the application of nitrogen. It might be that the plants failed to respond on these soils because of poor physical conditions or some other factors more limiting than availability of nitrogen.

In the second experiment almost all soils showed yield increases from fertilizer treatment. The yields were significantly higher for the 120 lb. nitrogen treatment. The data for the third and fourth experiments indicated that all soils responded significantly to the addition of nitrogen fertilizer. The check pots seemed to have reached quite a low level of nitrogen availability. This is comparable to soil exhaustion in the field when crops are grown continuously without using fertilizer. In the fifth experiment a highly significant F value was obtained for almost all the soils studied (30 soils). Yields obtained for treatments of 240 and 480 lb. nitrogen per acre applied to the previous crop were usually significantly high. This

again suggests that when nitrogen fertilizer is applied to the soil, a part of it, especially at higher levels, may be utilized by the subsequent crop.

It may be concluded from these studies that a soil whose rate of nitrate-nitrogen accumulation is below 80 p.p.m. is likely to respond to nitrogen fertilizer in the greenhouse. Furthermore, there is some residual effect if nitrogen fertilizer is applied at a high rate. And finally, on continuous cropping, the nitrogen availability in a soil is reduced and so there is increased response to nitrogen fertilization.

CONCLUSIONS

On the basis of the preliminary studies on nitrification, the following conclusions may be drawn:

1. Nitrification generally increases on leaching a soil and also on the addition of vermiculite.
2. Nitrification is a little higher at a moisture level of 50 to 60 per cent of the field capacity than at 40 per cent field capacity.
3. Nitrification is depressed by the addition of a nutrient solution containing major essential elements except nitrogen.

From the detailed study of the fifty soils the following additional conclusions appear to be justified:

1. Of all the methods tested for assessing the nitrogen requirements of the soils; namely, total nitrogen in the soil, total nitrogen in the plant material, nitrate-nitrogen initially present in the soil, per cent nitrogen mineralized to nitrate, available soil nitrogen by the Wisconsin method, available soil nitrogen by determining 'N' value, and nitrate-nitrogen accumulation in the soil, the last one mentioned, that is

nitrate-nitrogen accumulation, seems to be the best test. The determination of available nitrogen by calculating 'N' value was also, however, highly correlated with nitrogen responses. None of the tests was significantly correlated with the field data from the soils on which trials were placed in 1955 and 1956. However, the nitrification test gave a highly significant positive correlation value with check yields obtained from carefully selected nitrogen deficient fields in 1957 trials. Nitrification was also negatively correlated with nitrogen responses in some of the other field trials carried out in 1957. These relationships further indicate the usefulness of nitrate accumulation test in evaluating the nitrogen-supplying power of soils.

2. The recovery of nitrogen fertilizer added to soils in the greenhouse under the conditions of these experiments is on the order of 35 to 60 per cent. The unaccounted for nitrogen seems to be lost partly through denitrification. Some of it might be bound up with the increased root growth or in an immobilized form. A part of ammonium nitrogen might be fixed in the soil.
3. The recovery is generally a little higher when nitrogen is applied at lower rates and also when the physical condition of the soil is improved.
4. Soils with a nitrate-nitrogen accumulation less than 80 p.p.m. when incubated for two weeks at 28°C. respond in the greenhouse to a nitrogen application of 30 to 120 pounds of nitrogen per acre.
5. There is some residual effect on the subsequent crop from added fertilizer nitrogen, especially when it is applied at high rates.
6. Nitrogen availability decreases with continuous cropping, and probably more rapidly in the greenhouse than in the field, and in such cases soils will likely respond to nitrogen fertilization.

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APPENDIX 1

Determination of nitrate in soil by phenoldisulphonic acid method

1. Place 50 gm. of soil in a 16-ounce bottle.
2. Add 2 to 3 gm. of "G" elf carbon black, 245 ml. of distilled water, and 5 ml. of N. $CuSO_4$ solution.
3. Shake the contents on mechanical shaker for 15 minutes.
4. Add 0.2 to 0.5 gm. of $Ca(OH)_2$ and 0.5 to 1.0 gm. of $MgCO_3$ and again shake for 5 minutes.
5. Allow the bottle to stand for one-half an hour, filter the supernatant suspension using Whatman No. 5 filter paper.
6. Place an appropriate aliquot in an evaporating dish and evaporate to dryness at a temperature of 65°C. to 70°C.
7. Cool the dish, add rapidly 2 ml. of phenoldisulphonic acid. Rotate the dish so that the reagent comes in contact with the residue.
8. After 10 minutes, add 15 ml. of water and stir the contents.
9. When cool, add slowly 25 ml. of 1:2 ammonium hydroxide. Stir the contents again.
10. Transfer the contents to a 100 ml. volumeteric flask and make to volume with distilled water.
11. Select two colorimeter tubes which give the same reading when filled with distilled water.
12. Put a blank in position in a Bausch and Lomb colorimeter and adjust the amplifier control so that the pointer is at zero. Turn the light control knob to get 100 per cent transmission.
13. Read percentage transmission of the unknown. From standard curve determine p.p.m. of nitrate-nitrogen in the unknown.
14. Prepare standard curve by taking different aliquots of standard KNO_3 solution (.722 gm./10 liters) make to volume in 100 ml. volumeteric flasks. A standard curve thus prepared is given in Figure 6.

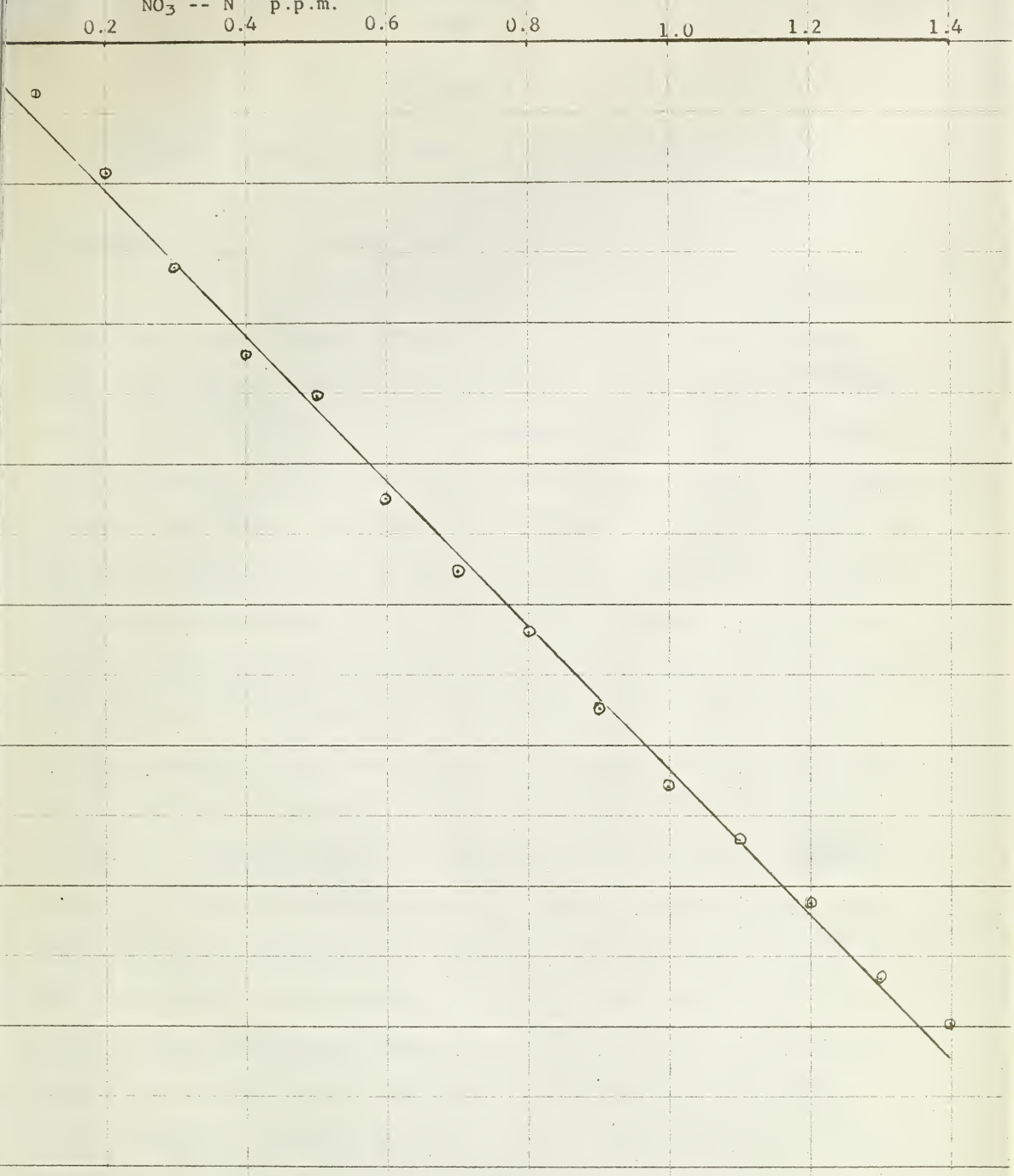

FIGURE 6. Relationship between nitrate-nitrogen in p.p.m. determined by the phenoldisulphonic acid method and per cent transmission using Bausch and Lomb colorimeter with wave length set at 405 mu.

APPENDIX 2

Determination of available nitrogen in soil by the Wisconsin method

(The following is a condensation of directions as given in a mimeographed outline obtained from the University of Wisconsin.)

Fill a 1/4 teaspoon measure (kitchen type) level full with 20-mesh soil (approximately one gram of silt loam) and place this soil in a regular 800 ml. Kjeldahl distilling flask. Add one gram of a mixture consisting of 20 parts of potassium permanganate and 80 parts of anhydrous sodium carbonate. (This latter may be measured with a standard 1/4 teaspoon measure, level full.) Then add 150 ml. of ammonia-free water, washing down any soil or reagent mixture sticking in the neck of the flask. To prevent difficulty from excessive foaming, add a piece of paraffin about the size of a pea. When many determinations are being made, foaming can be controlled more satisfactorily by applying a coating of "silicone" (Dow Corning Stopcock grease) to the inside surface of the upper 2/3 of the bulb of the flask. Application is made by means of a swab attached to the end of a stiff wire. Place the flask on a ringstand and connect it to a condenser. Bring to boiling with a flame or electric heater (Precision RH type with rheostat control works very well) adjusted to do this in exactly five minutes, and then continue the boiling for five minutes more, catching the distillate which contains the nitrogen liberated as ammonia in 10 ml. of ammonia-free water. Dilute the distillate with ammonia-free water to about 40 ml., add 2 ml. of Nessler's solution, dilute to 50 ml., mix thoroughly, and compare color with a standard containing 1 p.p.m. of nitrogen as ammonia, using regular Nessler comparison tubes. Each ml. of standard that it takes to match the whole 50 ml. of unknown represents one pound per million of soil or two pounds per acre of available nitrogen.

APPENDIX 3

Amperometric titration procedure for $K_2Cr_2O_7$ for organic carbon determination.

After digestion of the soil sample with standard $K_2Cr_2O_7$ (known volume) and concentrated sulphuric acid, the soil and the oxidizing solution were diluted to 1,000 ml. A 10 ml. aliquot was placed in a 250 ml. beaker, and to it were added about 120 ml. of water, 2 gm. of potassium iodide, 10 ml. of approximately 6.0 N. sulphuric acid. The iodine liberated was titrated amperometrically against standard sodium thiosulphate solution (approximately 0.002 N.) using a platinum electrode. Recording of reading was started when the microammeter read about 4.0 microampere. Sodium thiosulphate solution was added in about 0.2 ml. increments at a time and the readings on the burette and the microammeter were recorded. The addition of $Na_2S_2O_3$ solution was stopped when further additions no longer lowered the microammeter reading. A graph plotting microammeter readings on the y-axis and burette readings on the x-axis was drawn. The straight line projection which intersected the x-axis gave the quantity of $Na_2S_2O_3$ required for the titration. The method was found to be accurate, but it is lengthy. Moreover, it has the drawback of being useable only for very dilute solutions.

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